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CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE. E. L. MARK, DIRECTOR. — No. 152.

THE HEREDITY OF COAT COLOR IN MICE.

By Glover M. Allen.

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I. Introduction.

In the fall of 1900 the writer commenced a series of breeding experiments with a view to studying the inheritance of coat characters in the house mouse (*Mus musculus*) and its various domesticated varieties. This work has been carried on during the four years past under

the direction of Professor W. E. Castle, to whose guidance and inspiration is due whatever merit the present contribution may possess. The writer's earlier studies were made on the heredity of complete albinism in its relation to the character pigmentation. It shortly became evident that Mendel's principles of heredity, then being brought to notice by certain botanists, were applicable to the case, and this view has since been fully confirmed by more extended observations. The principles of segregation and resolution of characters among hybrids seem fundamental, and an attempt has been made in this investigation to throw further light on the mechanism of these processes. The writer is aware that the principles enunciated by Mendel, though far-reaching, must not be assumed necessarily to explain all hereditary phenomena, yet they appear to afford the key to much that has previously seemed enigmatical.

During the four years since the independent rediscovery of the Mendelian laws in 1900, by the botanists de Vries (: 00, : 00[a]) and Correns (: 00), a considerable literature has sprung up on the subject. The older experiments have been re-examined in the light of the new theory, and other experiments have been instituted to elucidate still further the phenomena of hybridization. At least three recent investigators have experimented with mice, and have published, in part, some of their results. Hence certain of the observations detailed in the present paper are not altogether new, but nevertheless are of value as being corroborative of results independently obtained. The fact that there are several workers in the same field is of further advantage in that an opportunity is offered for the comparison and coördination of results. In the following pages an attempt is made to explain the phenomena observed, according to the principles enunciated by Mendel; yet it is not urged that other explanations are impossible. It is simply a question of what hypothesis best explains the facts.

II. Varieties of Mice and Rats.

The house mouse (*Mus musculus*), as familiarly known in our dwellings and outbuildings, is probably of Eurasian origin, but has been carried by man into all parts of the civilized world. Its color is usually spoken of as gray, the "agouti" of fanciers, and though subject to some slight variation with age and habitat, is nevertheless of a fairly constant type. The pelage of a fully grown specimen taken at Cambridge, Mass., consists dorsally of two sorts of hairs; the one has a very fine black tip with a subapical ring of a light ochraceous color occupying about one-fifth the length of the hair, while the basal portion is dark plumbeous. Scat-

tered among these particolored hairs are others, less numerous but longer and entirely black, so that the combined effect is the "house mouse gray." The centre of the dorsal surface is slightly darker than the sides, while the ventral surfaces are covered (though more thinly) with hairs plumbeous at the base, but with the tips varying in different individuals from a dirty white to a very pale ochraceous tint. The ears, tail, and feet are sparsely covered with short, light gray hairs, and the skin of these parts is dark gray. The ochraceous bands on the particolored hairs of the upper surfaces deepen in tint with the age of the individual, so that old adults often have a rufous tinge on the flanks.

From gray house mice such as these it is supposed that the various domesticated breeds have arisen. Bateson (:03[b]) has published the partial results of an examination by Miss F. M. Durham of the pigments contained in the hair of house mice. These are found to be three: (1) densely opaque black, (2) less opaque brown, and (3) transparent yellow. All three pigments may coexist in the same hair, or certain hairs may contain only black and brown, others only black and yellow. The present writer also has found these three pigments in one or another of the strains of mice with which he has experimented. According as one, two, or all three of these pigments are present in greater or less degree, the mouse is referred by fanciers to a particular color type. Bateson has given a list of the types known to him, enumerating in all thirteen. These, in brief, are as follows:

(1) *Ordinary cinnamon*, or *agouti*, being the usual "wild gray," in which all three pigments are present in the hairs.

(2) *Golden agouti*, a distinctly tawny type, containing the yellow and brown pigments in the hairs, but not the black.

(3) *Sable*, of the agouti type, but with the flanks nearly clear yellow.

(4) *Blue-and-tan*, believed by Bateson to be the same as "sable" but with less of the black pigment.

(5) *Chocolate* or *plum*, containing the brown pigment alone.

(6) *Silver fawn*, a very light chocolate.

(7) *Yellow*, containing yellow only.

(8) *Cream*, a very light, or "diluted" yellow.

(9) *Black*, containing, according to Bateson, black and brown, the former not extending to the tips of the large contour hairs. The same author states that he has not seen a pure black, i. e., one without the brown pigment.

(10) *Blue*, a "dilute" form of black, the pigment granules being less numerous.

(11) *Albino*, in which there is no pigment whatever.

(12) *Black-eyed white*, of which two strains are noted, the eyes in one being a blackish-red.

(13) *Variegated*, in which "irregular, small spots of black or chocolate occur on a white ground."

So far as regards pigment, therefore, the known types of fancy mice are six, — namely, (1) *gray or "agouti,"* including the "*sable*," and *blue-and-tan* breeds, in which all three pigments are present; (2) the "*golden agouti*," in which brown and yellow are the only pigments present; (3) *black*, including "*blue*," in which there are only the black and chocolate pigments; (4) *chocolate*, containing brown pigment only; (5) *yellow* and *cream*, in which only the yellow pigment is present; (6) *albino*, lacking pigment both in the skin and in the eye.

The gray mouse may be looked upon as an individual in which are present the three pigment elements, — black, chocolate, and yellow. By the elimination of one of these elements there are produced the black-chocolate, or the chocolate-yellow combinations; if two elements are eliminated, either chocolate or yellow individuals result. A pure black is to be expected, for if the black pigment may be eliminated and so produce the golden-agouti effect, it would seem that it should also be able to appear alone.

Pied forms of these various types occur, and are generally referred to as *spotted* varieties.

Among rats (*Mus norvegicus* Erxl.) the gray coat bears a considerable superficial resemblance to that of the mouse, although hitherto no examination of its pigments appears to have been made. Moreover, so far as known, the pigment characters of the rat have undergone resolution only to the extent of producing black individuals. Pied and albino varieties are also well known.

The origin of the various breeds of fancy mice is to a considerable extent obscure. In a wild state, melanistic individuals of the house mouse are known to occur, and, according to Davatz ('93), are not uncommon in the valleys of Graubünden, Switzerland. They were first noticed there at about 1860, and were described by Fatio ('69) as a distinct species under the name of *Mus poschiavinus*. They were captured in houses and factories, which they inhabited in common with mice of the usual gray color, and they seemed to be about one-half as numerous as the gray individuals. Albino mice and rats are also not of rare occurrence in a wild state. According to J. W. Loudon ('50) albino mice were not uncommon, particularly in Savoy and some parts

of France, a half century ago, and other instances of their appearance here and there might be cited. The question may be raised, however, as to the likelihood of such sporadic cases being due to the introduction of albinos from other sources, and their subsequent escape. Nevertheless it is a matter of common knowledge that albinos may occur *de novo* among many species of mammals, as in deer, bison, squirrels, moles, and others (see Cantoni, '80).

It is thus not difficult to conceive how the albino and the black breeds now domesticated have originated. But the origin of other fancy varieties is not so clear. Thus Pallas (: 78) mentions three varieties: the albino with pink eyes, a black variety, and one gray with white spots. J. B. Fischer ('29) enumerates five different varieties of the house mouse: "totus albus oculis rubicundis," "totus niger," "albo-maculatus," "helvolus," "albus cinereo-maculatus." The first three varieties mentioned probably correspond with those recognized by Pallas; namely albino, black, and gray-white (perhaps also black-white). The two new varieties in Fischer's list are: (1) "helvolus," supposed by C. Carter Blake (in Fancy Mice) to be the same as isabella (yellow) and (2) "albus cinereo-maculatus," that is, white spotted with gray. Dehne ('55), writing of the house mouse found in Europe, mentions mice of the usual gray color above, but varying in the color of the belly from pure white to yellowish. The albino, he says, is common, though formerly a rarity. He mentions also a light yellow ("erbsen gelb") variety, with *pink* eyes, and a gray-white spotted variety.

The origin of the spotted varieties is unknown. Swinhoe ('70), in writing of the mammals of China and Formosa, states that black-white mice are often kept by the Chinese and that "these are brought from the Straits." The so-called dancing mice are usually attributed to Japan. They are smaller, and of more delicate proportions than the wild house mouse or its tame European varieties, and if actually of Japanese origin, may have been derived from one of the indigenous species closely related to *Mus musculus*. Ordinary dancing mice are black-white, but there occur also individuals which are wholly black or white, or which are spotted fawn-and-white, and have pink eyes (Darbishire, : 02). They are called dancing mice from a habit which they have of turning rapidly in circles of varying diameter, the direction of motion being usually clockwise. This habit is by some attributed to a nervous disorder, and by others to an abnormality of the semicircular canals of the ear. It is termed by the French "mouvement de manége". This breed is believed to have been domesticated by the Japanese for a considerable period, as evidence of

which Schlumberger ('94) figures and describes an ancient Japanese netzuke, or charm, carved in wood, and representing with great minuteness an entire family of dancing mice. The father and the mother, as well as four of the young, are spotted black-white, while of the four other young, two are entirely white and two entirely black. The two white young, as well as their black-white mother, have pink eyes; all the others have black eyes. The dancing character in mice of this variety is heritable, and, as pointed out by Castle (:03[d], p. 225), is transmitted quite independently of color characters.

Although the actual origin of the various breeds of mice is thus practically unknown, certain of the writer's experiments seem to throw light upon the method by which they may have arisen. For example, albino mice of unknown ancestry were in his experiments bred to gray house mice, and in the first generation only gray young were obtained, indistinguishable in outward appearance from their gray parent. Subsequently these gray offspring were bred *inter se*, and also back crossed with the albino stock. From both of these crosses there resulted, in addition to animals of the gray type, an occasional black individual, and two such black mice, when mated, produced only black young (or, if they contained albinism recessive, they produced albino as well as black offspring, in the Mendelian ratio, 1 : 3). It may be that in this case a segregation of the pigment elements has taken place in such a way that the yellow element has disappeared from certain individuals, and this segregation has been favored in some way by the cross made. On the other hand, it is not improbable that in this particular case the black character may have been transmitted directly through the albino grandparent without a segration of the compound gray character. This view will be explained in detail further on. The brown, or chocolate, element is present in these black mice, but is not evident to the naked eye except at such times as the regular moult of the pelage takes place, when the new hair is distinctly tinged with brown.

From these black mice *of house-mouse derivation* the writer has been unable, by crossing with the same albino stock, to obtain a further segregation of the pigments, but it would seem plausible to suppose that chocolate and yellow might yet be obtained from this stock by such a method. In the case of a black-white stock, however, further segregation was obtained. The black-whites used were purchased of a dealer by Professor Castle, under the name of Japanese mice, though they were not of the dancing variety. These mice, when bred to the same stock of albinos that was used in the house-mouse crosses, gave both gray young

and black young. By interbreeding the gray heterozygotes (or hybrids) there was produced, in addition to gray and black offspring, an occasional golden-agouti or a chocolate individual, these two sorts being about equally numerous. A similar result was obtained by crossing a gray with a black heterozygote, but these same black heterozygotes when bred *inter se* produced only blacks.

It is probable that the various color varieties of mice, as now kept by fanciers, have originated through segregation of elements found in the compound gray character, caused perhaps by crossing with dissimilar varieties. Long domestication and the conditions incident to confinement have very likely been effective in aiding this so-called "breaking up of the type."

It may be of interest to mention here what appears to be a pathological variety of the house mouse, namely, the so-called "rhinoceros mouse." This appears to have first been figured and described by Gaskoin ('56), whose colored plate represents an animal of the size of the common mouse, but entirely devoid of hair, except for a few whiskers. The skin, however, is thrown into a series of transverse corrugations, and extends along the sides as a broad fold running from the anterior to the posterior limbs and loosely enveloping them. This character and the generally wrinkled appearance of the skin give the animal somewhat the appearance of a diminutive rhinoceros. According to Gaskoin, no vestige of hair or hair follicles could be discovered in microscopic sections of the skin. He states that two individuals of this sort, a male and a female, were captured by a laborer about a straw stack which stood in a wood not far from Taplow Paper Mills, England. The female was pregnant and in a week had five young, all of which were of the same "rhinoceros" type. Gaskoin also mentions a similar specimen which was captured in the fireplace of a room, in 1820, and is preserved in the museum of the College of Surgeons, England.

FIGURE 1.

The present writer obtained a mouse exhibiting this same condition

(Figure 1). It was captured in a house in Boston, where it had been seen with a white and a black-white mouse. Unfortunately it died before any young could be obtained from it. Its skin was soft, and it was similar in every way to those figured by Gaskoin, save that the ears had a few hairs on their distal portion, and there were a number of whiskers.

During the course of the writer's experiments, a certain normally haired female gave birth to a litter of young, and these, after acquiring their first coat of hair, became sick and perished one by one, till finally a single individual of the litter remained. This mouse, while still very young, lost all its hair, except for a small amount on the ears, nose, feet, and tail. It soon began to develop the transverse corrugations and the lateral fold of skin, and would doubtless have become a "rhinoceros mouse," had its career not been cut short at this interesting stage. It is clear that this condition is a pathological one, and there are indications that it is heritable, but exact tests of this have as yet proved impossible.

III. Care and Management.

A few words respecting the care and management of mice may not be without value to those who contemplate experimenting with these animals. Tame white mice and rats seem to have little desire to escape from their boxes, and hence cause little trouble. But wild individuals are very timid and at the first alarm are apt to rush wildly for the nearest opening, and escape. For this reason, it was found that a double compartment cage, with separate doors for each compartment, was the best. A small opening at the far end of the partition between the compartments allows the inmates to gain the shelter of the opposite chamber while one side of the cage is being examined or cleaned. As the results of experiments with various sorts of cages, Professors Mark and Castle designed one which has been used in the work at the Harvard Zoölogical Laboratory for the past two years with great satisfaction. As the basis for the cage (Figure 2), a wooden tray is used, of the standard size employed throughout the Museum of Comparative Zoölogy, viz., 27½ inches long, 18 inches wide, and 3½ inches high, outside measurements, made from half-inch stock. At the back of this tray, three upright posts 13 inches high are erected, one at either end and a third at the middle. Cross pieces connect the tops of these posts, and two slanting side pieces run from the tops of the end posts to the front of the tray. The sides as well as a central partition are of wire netting, and the two doors, hinged to the top, are wooden frames covered on the inner side with netting. Racks were constructed, designed to hold ten or twenty of these

boxes in five tiers. Thus an economy of space was secured, while the compactness of the system made feeding and cleaning easier. The floors of the cages are kept covered with clean sawdust, and wooden berry baskets, one to each compartment, inverted and filled with cotton, serve for nests.

As for food, bread and milk are used as a staple, care being taken that the mixture should not contain more liquid than the bread will absorb. Oats and bits of vegetable, as well as green grass, afford a welcome variety.

In work of this sort, where it often becomes necessary to test the same

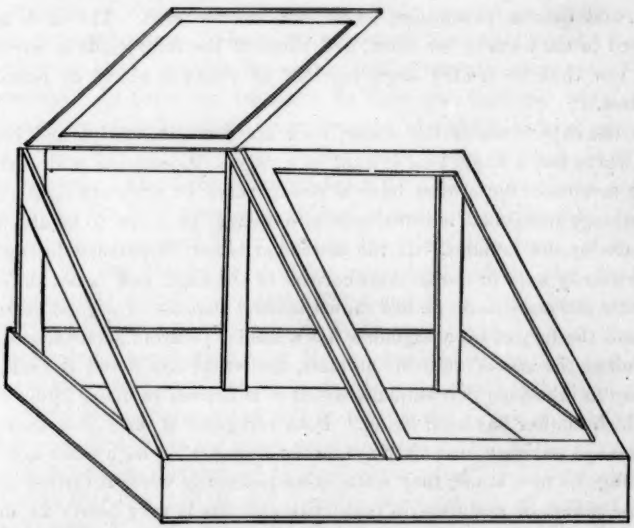


FIGURE 2.

mouse with various other individuals, some means of marking the animals is needed, so that a given individual may be identified readily from among similarly colored mice. To this end the writer has used the system employed by Professor Castle in connection with guinea-pigs and rabbits, namely, that of punching small holes in the ears. The left ear may be used for tens, the right for units. A small circular hole at the anterior base, tip, or posterior base, stands for 1, 2, or 3, respectively. A scallop or notch in the same places represents 4, 5, or 6, respectively; while by using two notches, combinations standing for 7, 8, or 9 are readily made. An ear unpunched stands for 0. After the numbers from 1 to 99 have

been exhausted for numbering the mice, the individuals of the second hundred may be marked in like manner, care being taken to avoid giving the same number to two mice of the same color. For numbers of the third hundred, a round hole may be punched in the centre of the left ear, and for those of the fourth hundred, a similar hole in the right ear. With care, these marks may be accurately placed, and this with no apparent inconvenience to the animals. The mice may be recorded serially in a blank-book kept for the purpose, and the writer has also found it of advantage to use a separate card for each animal. For this purpose library cards may be used, the animal's pedigree entered on the back, and data as to matings, litters, etc., on the front. The cards may be used in the form of an index, and those of the individuals in any one cage can thus be readily kept together or changed about as occasion requires.

In the experience of the writer, mice are found to thrive and breed best where but a single pair is kept in a cage. In common with certain other mammals, these mice have a strong sense of property rights, and if a strange individual is introduced into a cage, he is apt to be attacked at once by the inmates. If the newcomer is not despatched forthwith, he is usually kept in the farthest corners of the cage, and is not suffered to enter the nests until he has shown himself capable of a good defence, or until the fury of his antagonists has abated. To avoid such encounters, as well as the loss of valuable animals, the writer has found it sufficient simply to introduce two animals, which it is desired to mate, into a cage in which neither has been living. Both recognize at once that they are on strange territory, and after cautiously approaching each other and examining the new home, they settle down peaceably without further ado.

The period of gestation in both mice and rats is very nearly 21 days, and the female is in heat again at the birth of a litter (Sobotta, '95). The young should be weaned at three weeks old, for, if allowed to remain longer with the mother, they become poorly nourished and puny from overcrowding of the pen. Not infrequently the male will devour the young, at the time they are born, if he is not removed. More rarely a female mouse will devour her entire litter.

As the young are born blind and naked, several days must elapse before it is possible to determine their coat color. Albinos can be distinguished at birth, however, since their eyes are unpigmented, while individuals which are to become colored have dark eyes at birth, the pigment showing distinctly through the overlying skin. Pigmented animals having pink eyes could not, of course, be distinguished from

complete albinos at this stage, but none of this sort have been obtained in these experiments.

Mice may be mated at the age of three months, and they will continue to breed until a year old or slightly longer. But although they may live to be 15 or 18 months old, they are much less prolific in the latter months of their life. Moreover, in the writer's experience, they rarely breed so often as once in three weeks, although they are capable of so doing.

IV. Mendel's Laws of Heredity.

Mendel's great discovery of the principles in heredity of dominance and segregation of characters is now so generally known as hardly to need extensive notice here. These two important laws were first set forth by Mendel in 1866, though for nearly half a century they passed quite unnoticed. In 1900 the botanists de Vries and Correns, working independently of each other, again brought to light Mendel's principles, and were able to give them further confirmation through their own experiments. The three following years have seen a keen and growing interest in the field thus opened, and already a considerable body of literature has appeared for or against the Mendelian laws. A full exposition of the Mendelian doctrine may be found in the works of Bateson (:**02**) and Castle (:**03**^{b}, :**03**^{d}), and it is from these that the following brief statement is principally drawn.

In his experiments with peas, Mendel established the fact that when two varieties are crossed, whose seeds are respectively yellow and green, the hybrid seeds produced are yellow, that is, the yellow color of cotyledon is dominant, while the green color does not appear in the cross-breds, though it will be represented in their germ cells. If D represent the dominant character and R the recessive character set off against it, we may express Mendel's result by this formula (1): $D \times R = 4D(R)$,* the parenthesis indicating that the enclosed character is present in the germ cells but does not appear in the soma. In such cases of simple dominance, the first filial generation, F_1,† resembles in external appearance the parent possessing the dominant character. That this resemblance does not signify identity in character may be shown by breeding *inter se* the D(R) hybrids obtained from the above cross. Mendel proved that for his peas the hybrids, D(R), produced germ cells D and

* In this equation the symbols at the left of the sign of equality indicate the character of the parents, those at the right the character of their offspring.

† This convenient notation, suggested by Bateson (:**02**), will be employed throughout this paper.

R in approximately equal numbers. This result is probably brought about by the expulsion, in maturation, of the D or the R character from the germ containing these two elements. This phenomenon is the so-called principle of segregation. If one hybrid be fertilized by another like hybrid, there will thus be possible, according to the laws of chance, *two* combinations of a D with an R gamete to *one* each of a D with a D and an R with an R, thus:

$$\begin{array}{r} D + R \\ D + R \\ \hline D + 2D(R) + R \end{array}$$

This result may be expressed by formula (2):

$$D(R) \times D(R) = D + 2D(R) + R.$$

Generation F_2 will thus consist of three sorts of individuals: (*a*) individuals D, which are pure dominants and reproduce their kind only; (*b*) individuals D(R), which, though indistinguishable in somatic characters from those of class (*a*), are nevertheless heterozygotes and, like their parents, produce gametes D and R in equal numbers; and (*c*) individuals R, which have the recessive character alone, and when paired with other R individuals produce only R offspring.

For class (*a*), if kept by itself, we may then construct formula (3): $D \times D = 4\ D$; and for class (*c*) formula (4): $R \times R = 4\ R$. The formula for class (*b*) is of course the same as that for their parents, the primary hybrids, viz., formula (2) above. In addition to these crosses, the D(R), or heterozygous, individuals may be back-crossed with the original parent forms. Thus, if the D(R) animal, producing gametes D and R in equal proportions, be bred to one of the pure dominant type, producing gametes D and D, there will be two sorts of combinations possible, one of which will be a combination of D with D, the other a combination of D with R. The chances for the occurrence of each are equal. The result may be expressed by formula (5): $D(R) \times D = 2D(R) + 2D$. In external appearance, the entire progeny of this cross may be similar, but the existence of the two sorts of individuals may be demonstrated by crossing each with the recessive form, R. In the case of the D individuals, such a cross will produce only heterozygotes, D(R), in accordance with formula (1). But the D(R) class, producing equal numbers of D and R gametes, on being crossed with the recessive type, will give in equal proportions the two sorts, D(R) and R individuals. This result we may express by formula (6): $D(R) \times R = 2D(R) + 2R$. Thus in a cross of two heterozygotes, there are obtained, — formula (2),— in addition

to a heterozygous class similar to the parents, two pure classes, each reproducing respectively the one or the other parent type. On the other hand, when a heterozygote is back-crossed with either of the pure parental types, — formulae (5) and (6),— no new forms result, but there is simply a reproduction of the two which united in fertilization.

For convenience in reference these formulae of Mendelian inheritance may be brought together as follows:

To the left of the sign of equality is indicated the character of the parents mated; to the right, the classes and numerical proportions of the offspring to be expected.

(1) $D \times R = 4D(R)$
(2) $D(R) \times D(R) = D + 2D(R) + R$
(3) $D \times D = 4D$
(4) $R \times R = 4R$
(5) $D(R) \times D = 2D\,(R) + 2D$
(6) $D\,(R) \times R = 2D(R) + 2R$

A similar set of formulae may be deduced for cases in which the dominant character is a mosaic of the two characters which, if occurring separately, are to each other as dominant and recessive. Thus the character of a spotted mouse (pigmented, but with white areas at certain places) is dominant over that of a complete albino, and the pigmented heterozygotes may produce gametes of two sorts, the one bearing the character partial albinism, the other bearing the character complete albinism. The various combinations possible for these two characters may be expressed by the following formulae:

(1*a*) $DR \times R = 4DR(R)$
(2*a*) $DR(R) \times DR(R) = DR + 2DR(R) + R$
(3*a*) $DR \times DR = 4DR$
(4*a*) $R \times R = 4R$
(5*a*) $DR(R) \times DR = 2DR + 2DR(R)$
(6*a*) $DR(R) \times R = 2DR(R) + 2R$

These formulae indicate the results of various matings in cases of simple dominance and segregation. In cases where compound characters become resolved and the elements reunite again in cross-breeding, it is not certain that the relations are quite so simple. Nevertheless, the results so obtained seem to indicate that here, too, segregation does take place in a more or less definite way.

V. The Heredity of Albinism.

A. Complete Albinism.

1. ***House mice and albinos.*** In a preliminary paper (Castle and Allen, :03) Professor Castle and the writer have shown that complete albinism in mice and rats is a recessive character in a Mendelian sense, and our observations corroborate Cuénot's (:02) results along similar lines. The writer bred wild house mice, captured in stables and houses in Cambridge, to a stock of albino mice obtained from a Boston dealer. Nothing could be learned as to the ancestry of these albinos, but when bred *inter se* they had produced only albinos. As a result of this cross of wild gray with albino mice, only pigmented individuals were obtained. By breeding albino males to female house mice, eight litters were secured, there being a total of 28 young. The average number of young produced at a birth was thus $3\frac{1}{2}$, and the commonest number was 3 or 4. There was one litter of 7 and one of 6, while a third consisted of but 2 individuals. By the reciprocal cross, in which the gray house mouse was the male, and the albino the female parent, 38 young were produced in nine litters, an average of $4\frac{2}{9}$ to a litter. The sex was ascertained of 46 of these 66 mice, and there were found to be 21 females and 25 males, an excess of about 8 per cent of males. This is in accord with the work of Schultze (:03), who usually obtained a slight excess of males among the offspring of his white (albino) mice.

Several of the cross-breds produced by the matings described were paired. The Mendelian expectation in this case is, by formula (2), that a quarter of the progeny will be albinos, a quarter will be pure dominants, and the remaining half will be, like their parents, heterozygous, pigmented but containing the albino character in a recessive condition. Quantitatively, this expectation was not precisely realized. For of the 69 mice produced, theoretically 17 should have been albinos, while 52 should have been pigmented. There were actually 25 albinos and 44 pigmented individuals, or 36 per cent albinos and 64 per cent pigmented. The excess of albinos is thus 11 per cent, or there are about half again as many albinos as expected.

The distribution of the young by litters in this generation is shown in Table A.

Disregarding the first two litters in which the precise Mendelian ratio of pigmented and albino young is realized, we find that six of the eight remaining lots show an excess of albinos ranging from 0.25 to 4 per litter, or an average of less than two (actually 1.5). Only two litters con-

TABLE A.

	Pigmented.	Albino.	Expected No. Pigmented.	Expected No. Albino.	
Litter 1 } " 2 }	9	3	9	3	exact agreement.
" 3	4	..	3	1	excess of pigmented.
" 4	5	3	6	2	" albino.
" 5	4	2	4.5	1.5	" "
" 6	2	3	3.75	1.25	" "
" 7 } " 8 }	8	8	12	4	" "
" 9	5	2	5.25	1.75	" "
" 10	3	3	4.5	1.5	" "
" 11	4	1	3.75	1.25	" pigmented.
Total	44	25	51.75	17.25	

tained an excess of pigmented individuals, and the excess is very slight, 0.25 in one case, and 1 in the other, an average of less than 1. The entire excess of albinos being 7.75, the average excess is thus less than one for each of the nine litters which show deviation from the Mendelian ratio. To be sure, the totals are not large, and the results may be purely a matter of chance in the union of the gametes, yet the deviation may have some significance which has not yet been fully appreciated. Thinking that the production of an excess of albinos might be an individual peculiarity of the parents, wherein an unequal number of pigment and non-pigment gametes were given off, two of the heterozygous, F_1, males were bred to albinos; but these produced an excess of *pigmented* individuals, there being in 17 litters 35 pigmented mice as against 23 albinos, where — according to formula (1) — equality is expected. Curiously, the excess of albinos in the litters from cross-breds nearly offsets the shortage in the lots obtained by back crossing with the albino parent. Thus in the first case, out of a total of 69 young, we expect 17 to be albinos, and obtain 25. In the second case, 29 albinos are expected, and only 23 occurred. In all, therefore, 48 albinos were produced, where 46 are

expected. The deviations from the Mendelian ratios may, therefore, be due simply to the relatively small numbers of young obtained.

Cuénot (: 02) in similar experiments procured a much larger number of mice, and his figures are much more nearly in accord with the theoretical expectation. By breeding together the F_1 heterozygotes, he obtained 198 pigmented mice and 72 albinos, or 26.6 per cent albinos. By back-crossing the heterozygotes with albinos, Cuénot obtained an approximate equality of pigmented and of albino mice, but the precise numbers are not given.

The pigmented animals obtained by interbreeding the F_1 heterozygotes should be of two sorts according to Mendelian principles, the one of pure dominants, the other of heterozygotes; and these two classes should be to each other numerically as 1 : 2. No actual test of this numerical ratio has as yet been made in the case of mice. To make such a test, it is necessary to breed each of the F_2 pigmented individuals to an albino or to a heterozygote (containing the albino character recessive), and a sufficient number of young must be so obtained to determine whether or not the particular individual is producing germ cells having the albino character. It is obvious that the cross with an albino is preferable, in this case, to the cross with an individual known to be heretozygous. For the albino, if bred to an animal containing the albino character recessive, will (by formula 6) produce 50 per cent of albinos, whereas from two heterozygous animals, only half as many are to be expected. The writer has tested 10 of the pigmented mice of generation F_2 by breeding them to albinos. Five of these individuals produced only pigmented young, 8, 11, 9, 5, and 11 respectively. We may therefore conclude that they were in all probability of the class D, or "extracted" (Bateson) dominants. Each of the five other animals of generation F_2 produced both pigmented and albino offspring when bred to albinos. They were, then, of the class D(R). The totals of their litters are 23 pigmented, 26 albino, offspring. It is therefore plain that, qualitatively, the Mendelian expectation is realized, in the case of generation F_2, where the three classes, D, D(R), and R should be present in the proportion 1 : 2 : 1. The fact that the ten mice of classes D and D(R), although selected at random, were 5 of them of class D and 5 of class D(R), instead of being one-third D and two-thirds D(R), may be not without significance in this particular case, wherein there is some slight evidence of irregularity. Yet the result may be purely a chance occurrence, for the numbers are small.

It is of interest to examine the separate litters making the above total of 23 pigmented and 26 albino young (see Table B).

TABLE B.

Litter.	Parents.	Albino.	Pigmented.
1	♀ 242* × albino	3	2
2	" "	3	2
3	" "	3	..
4	♂ 246 × albino	3	3
5	" "	4	4
6	♀ 210 × albino	3	
7	♀ 208 × albino	1	6
8	" "	3	1
9	" "	..	1
10	♀ 212 × albino	3	3
Total		26	23

Only three of the ten litters (Nos. 4, 5, and 10) show the expected equality. Two of these were from the same pair, and as in the case of the third litter, represent all the young obtained from the parents. Evidently each of the two heterozygous parents was producing equal numbers of D and of R gametes. In case of the pair producing the first three litters, there is an excess of 33⅓ per cent of albinos, and one entire litter of three contained no pigmented animals at all. The heterozygous parent, if we may judge from the small number (13) of young produced, furnished more albino than pigment gametes. The opposite seems to have been the case with the pigmented parent of litters 7, 8, and 9, which aggregate 4 albinos, 8 pigmented offspring. Nevertheless the result is doubtless a chance one, since, although the first litter shows a shortage of albinos, the second litter presents an excess. The total result, 26 : 23, is a close approximation to the Mendelian expectation with the slight excess in favor of the albinos. Thus it appears that although, in individual lots, there may be a considerable irregularity in the proportions of the two sorts of gametes produced by the heterozygote, yet in the long run the 1 : 1 ratio is practically realized.

* Different individuals are distinguished by numerals, as stated on page 69.

Cuénot (: 02) also tested the pigmented mice of generation F_2 which he obtained by breeding *inter se* the heterozygotes of generation F_1. This he did by simply interbreeding these pigmented animals. In this case, according to the Mendelian formulae, three sorts of unions are possible: (1) D × D, (2) D × D(R), and (3) D(R) × D(R). From the first two combinations no albinos will be produced; from the third, there should be produced 25 per cent albinos. Cuénot found these expectations realized, for of a number of the pigmented mice selected at random, about one-half produced only pigmented young (189), and the other half produced the expected 25 per cent of albinos, the actual numbers being 162 pigmented: 57 albinos, or 26 per cent albinos. In case of the mice whose union produced no albinos, either one or both animals of each pair must have been of the D class. If one-half were of the D class and the other half of the D(R) class, the precise Mendelian expectation would be realized. Since at least one-half of all the pigmented mice were certainly known to be D(R) because they produced albinos, it is probable that, in those unions which produced no albinos, one at least of the two parents mated was a pure D, the other being probably in some cases heterozygous, in other cases pure.

The two tables, C and D, show the total numbers of pigmented and of

TABLE C.

	Parents both D(R).	Pigmented Young.	Albinos.	Expected No. of Albinos.
1	♂ gr. 48, 49, 56 × ♀ gr. 50, 51, 52	44	25	17.25
2	♂ gr. (bl.-wh. × alb.) × ♀ gr. (house m. × alb.) .	19	7	6.50
3	♂ gr. 143 × ♀ gr. 229	4	2	1.50
4	" " "	2	3	1.25
5	" " "	5	..	1.25
6	" " "	1	..	.25
7	♂ bl. 246 × ♀ bl. 242	5	2	1.75
8	" " "	..	2	.50
9	" " "	1	..	.25
10	♀ bl. 457 × ♀ bl. 456	..	1	.25
		81	42	30.75

TABLE D.

	Parents: one D(R), one R.	Pigmented Young.	Albinos.	Expected No. of Albinos.	
1	♂ gr. 51 × ♀ alb. . . .	4	..	2	
2	" " . . .	..	3	1.5	
3	" " . . .	1	2	1.5	
4	" " . . .	2	..	1	
5	" " . . .	1	..	.5	
6	" " . . .	2	1	1.5	
7	" " . . .	4	2	3	
8	" " . . .	1	1	1	
9	" " . . .	..	1	.5	
10	" " . . .	4	..	2	
11	" " . . .	1	..	.5	20 p. : 10 alb.
12	♂ gr. 56 × ♀ alb. . . .	1	1	1	
13	" " . . .	2	2	2	
14	" " . . .	1	1	1	
15	" " . . .	1	1	1	
16	" " . . .	3	1	2	
17	" " . . .	3	1	2	11 p.: 7 alb.
18	♂ alb. 145 × ♀ gr. 52 .	2	5	3.5	
19	" × ♀ gr. 50 . .	2	1	1.5	
20	♂ alb. 237 × ♀ gr. 210 .	1	3	2	
21	♂ alb. 235 × ♀ gr. 208 .	6	1	3.5	
22	" " .	1	3	2	
23	" " .	1	..	.5	8 p. : 4 alb.
24	♂ bl. 246 × ♀ alb. 254 .	3	3	3	
25	" " .	4	4	4	7 p. : 7 alb.
26	♂ gr. 376 × ♀ alb. 255 .	4	2	3	
27	" " . .	1	3	2	5 p. : 5 alb.
28	♂ alb. 246 a × ♀ bl. 242.	2	3	2.5	
29	" " .	2	3	2.5	
30	" " .	..	3	1.5	4 p. : 9 alb.
31	♂ alb. 277 × ♀ gr. 212.	3	3	3	
32	" " .	3	1	2	6 p. : 4 alb.
33	♂ alb. 246 a × ♀ bl. 377 .	3	2	2.5	
34	" " .	4	2	3	7 p. : 4 alb.
35	♂ alb. 412 × ♀ bl. 377 .	3	3	3	
36	♂ gr. 376 × ♀ alb. 441 .	3	..	1.5	
37	♂ alb. 428 × ♀ ♀ 427 a, 429	5	2	3.5	
		84	64	74	

albino young obtained by the writer from all litters in which the pigmented parent or parents were of house-mouse and albino ancestry, and include the lots previously mentioned as well as several not elsewhere noted.

Table C shows that in a total of 123 young there is an excess of about 11 albinos (9 per cent) over the expected number, and this preponderance of the recessive character is seen to be especially marked in generation F_2 (from ♂♂ gr. 48, 49, 56, mated with ♀♀ gr. 50, 51, 52), where it is about 11 per cent. The additional lots, however, reduce this excess to 8 per cent in the total, and it would doubtless be found that larger numbers would show still closer approximation to the theoretical result, as indeed the experiments of Cuénot (:02) show.

Table D is of more particular interest, since it gives the results of back crossing with an albino a pigmented animal one of whose parents was an albino. Consequently, by Mendelian formula (6), the pigmented mouse is assumed to produce in the long run equal numbers of gametes bearing the pigment and the albino characters respectively. It is evident that if such an animal be bred to an albino, all the gametes it produces that bear the albino character will unite with those of a similar sort furnished by the albino mate, and *albino* young will result. Further, all the gametes it produces that bear the pigment character will also unite with those of the albino, but pigmented young will be produced, each of which will contain the albino character recessive. It is thus possible to determine how many gametes of each sort are produced by the heterozygote at each union, or, at least, how many of them unite with those of a second animal to form new individuals.

In the case of the heterozygous male, No. 51, thirty young were obtained in eleven litters by white females. Instead of the anticipated equality of pigmented and albino mice, the former class stands to the latter as 2 : 1. Most of the litters are small, three consisting each of but a single individual, and but one of these is an albino. Two litters consist each of two young, and in the one case both are pigmented, while in the other there is one pigmented and one albino young. This last litter is the only one of the eleven in which the expected equality of the two classes is realized. There are three litters of three young each. One of these is of albinos only. The other two taken together give an equality of the two classes, the excess in the one exactly counterbalancing the shortage in the other. Two litters, each of four young, contain no albinos at all, while the single litter of six contains four pigmented to two albino young, a ratio again of 2 : 1.

Male heterozygote, No. 51, gave six litters by albinos, and in four of these the exact Mendelian proportion, 1 : 1, is maintained with a total of ten young. In the remaining two litters three pigmented young are obtained to one albino. The total excess of pigmented over albino mice in this case is thus but two in a total of 18 young. A third heterozygote, ♀ gray 208, produced three litters, in two of which there was an excess of pigmented young, while in the third there was an excess of albinos, a total of eight pigmented to four albino young. Two other animals produced each two lots of young; in the case of one there is Mendelian equality in each litter, while in the case of the other, a shortage of albinos in one litter is exactly offset by an excess in the second litter. The remaining cases show a similar state of affairs, for a single large or small litter may contain equal numbers of pigmented and of albino young, while subsequent lots show an excess of the one or the other sort in varying degrees, amounting in some cases to a total exclusion of the pigmented or of the albino class, and this too in litters of as many as three or four young. The most extreme case obtained was one in which there was but one albino in a litter of seven mice, the expectation being equality of albino and pigmented individuals.

It is evident from this table that there is a considerable variation in the relative numbers of gametes of each class brought by the heterozygote to each union. Frequently there is an exact numerical equality of the two classes in separate litters, as is theoretically expected on Mendel's assumption that a heterozygote produces gametes of the two sorts in equal numbers. In other cases the gametes of such an individual produced at one time, or at least all which unite with those of another animal to produce young, may be entirely of the one class or the other, while between these two extremes are found various degrees of variation in the relative proportions of the two sorts. This variation appears to be quite independent of sex. The numerous deviations from the 1 : 1 ratio tend to counterbalance one another, often to a remarkable degree, so that as the numbers obtained become larger, the approximation to the theoretical ratio becomes constantly closer, and *in the long run* we may say that the heterozygote *does* produce equal numbers of gametes of the two classes considered.

In order to show that Mendelian ratios are due simply to the chance combinations of gametes, the following experiment, suggested by Professor Castle, was tried. Equal measured quantities of small white beans were placed in two bags of the same shape and size. One-half the beans in each bag were marked with a spot of red ink, and the other half were

left unmarked, so that the former stood for gametes having the character pigmentation, and the latter for gametes having the character albinism. The contents of each bag, when thoroughly mixed, were supposed to represent an indefinite number of the two sorts of gametes produced in equal proportions by a heterozygote. If, now, a single bean be taken at random from each bag, three combinations are possible: (1) both beans may be spotted, representing a pure D individual; (2) one may be spotted, the others unspotted, representing a heterozygous, D(R), individual; or (3) both beans may be unmarked, representing an albino, R. For comparison the same number of drawings was made as there are individuals represented in Table G (page 84) of the progeny of heterozygotes from spotted and albino parents. The total number of these young was 214, of which 159 were pigmented and 55 were albinos, so that the two classes are practically as 3 : 1. Three series of drawings were made. In the first and second of these, the number of beans in each bag was indefinite, but in the third series, the beans representing the gametes of the female parent were made only twice as many as the number of young actually occurring in any given litter of the table and, of course, represented equal numbers of the two sorts in each case. The totals for each of the three series of drawings agreed very closely with the numbers actually obtained with the mice, the agreement being almost perfect in the case of the third drawing, in which the conditions of the experiment were made to correspond most closely with those in the mice. In a small number of consecutive drawings there was sometimes a considerable excess of one class or another over its expected ratio, but these discrepancies tended to balance one another in the long run, just as observed with the mice. Table E gives a summary of these results.

TABLE E.

	Pigmented, D D(R)	Albino, R
Result with the mice (Table G)	159	55
First drawing, number of gametes indefinite	59 + 110 = 169	45
Second " " "	48 + 113 = 161	53
Third drawing, gametes of female double the number of offspring	53 + 107 = 160	54
Expectation	53.5 + 107 = 160.5	53.5

This table shows that the chance unions of the two sorts of gametes, when produced in equal proportions by both parents, give the three possible classes, D, D(R), and R in approximately the proportions 1 : 2 : 1.

A similar series of drawings was made for Table H (page 87), which represents the offspring of heterozygous and albino parents. In this case, where an equality of the two classes is expected, one bag contained only unmarked beans representing gametes of the albino parent. The following table (F) gives the results obtained:

TABLE F.

	Pigmented, D(R).	Albino, R.
Result with the mice (Table H)	69	69
First drawing, number of gametes indefinite	58	80
Second " " "	72	66
Third drawing, gametes of female double the number of offspring	74	64
Average for three drawings	68	70
Mendelian expectation	69	69

2. *Spotted mice and albinos.* In a former paper it has been shown (Castle and Allen, :03) that the piebald mouse, having areas of pigmented and non-pigmented integument, is a distinct type, or "mutation," and the gametes formed by such an animal are in the nature of a mosaic of the two alternative characters. Such mosaic gametes act in heredity as unit characters, and the pigment-albino mosaic is dominant over gametes representing complete albinism. Crosses in which one of the parents is a spotted animal and the other a complete albino may therefore be legitimately considered in investigating the behavior of the unpigmented condition toward a character dominant over it.

In the experiments of the writer, a number of young were obtained by breeding together pure mosaics and albinos. The result was in every case complete dominance of the pigmented condition; in most cases the recessive element of the mosaic disappeared altogether from the soma. The behavior of the mosaic condition will be taken up in greater detail farther on. The important point in the present connection is that the albino character contained in one of the conjugating gametes becomes recessive towards the mosaic character, so that from the union just de-

TABLE G.

No.	Parents of Spotted Stock.	Pigmented Young.	Albinos.	Expected No. of Albinos.
1	♂ gr. 31 a × ♀ gr. 45	2	..	.50
2	" "	3	1	1
3	" "	..	1	.25
4	" × ♀ gr. 33	2	1	.75
5	" "	..	1	.25
6	" "	1	3	1
7	" "	3	2	1.25
8	♂ gr. 82, 84 × ♀ gr. 81, 88 . .	2	..	.50
9	" " . .	1	..	.25
10	♂ gr. 31 a × ♀ gr. 33	2	..	.50
11	" "	2	2	1
12	♂ gr. 82, 84 × gr. ♀ 81, 86 . .	3	1	1
13	" " . .	3	..	.75
14	" " . .	2	1	.75
15	" " . .	1	..	.25
16	" " . .	2	..	.50
17	" " . .	1	2	.75
18	" " . .	2	..	.50
19	" " . .	1	..	.25
20	" " . .	3	1	1
21	♂ bl. 99 × ♀ bl. 94, 98, 101 . .	4	5	2.25
22	♂ gr. 1 × ♀ gr. 3	1	2	.75
23	♂ gr. 1 × ♀ gr. 68	3	1	1
24	" "	2	1	.75
25	♂ gr. 4 × ♀ gr. 64	3	1	1
26	" "	3	1	1
27	" "	6	..	1.50
28	♂ gr. — × ♀ gr. 87	5	4	2.25
29	" "	5	..	1.25
30	♂ gr. 40 × ♀ gr. 38	2	2	1
31	" "	1	2	.75
32	" "	4	1	1.25
33	♂ bl. 103 × ♀ bl. 106	5	1	1.50
34	" "	5	1	1.50
35	♂ gr. 82 × ♀ gr. 81	2	1	.75
36	" × ♀ gr. 81, 86, 114 . .	3	..	.75

TABLE G (*continued*).

No.	Parents of Spotted Stock.	Pigmented Young.	Albinos.	Expected No. of Albinos.
37	♂ bl. 99 × ♀ bl. 98	2	..	.50
38	♂ bl. 342 × ♂ bl. 344	5	1	1.50
39	" "	4	2	1.50
40	" "	3	1	1
41	♂ ch.-wh. 402 × ♀ bl.-wh. 403 .	4	1	1.25
42	♂ gr. 369–374 × ♀ gr. 375 . .	2	..	.50
43	♂ gr. 409 × ♀ gr. 411	5	2	1.75
44	♂ bl. 321 × ♀ bl. 316	3	..	.75
45	♂ ch. 392 × ♀ ch. 393	3	2	1.25
46	♂ gr. 374 × ♀ gr. 418, 419, 421 .	4	..	1
47	♂ gr. 369, 371, 374 × ♀ gr. 375 .	3	..	.75
48	♂ gr. 409 × ♀ gr. 411	5	3	2
49	♂ gr. 374 × ♀ gr. 418, 419, 421 .	7	1	2
50	♀ bl. 92 × ♀ gr. 91, 93, 97 . .	3	..	.75
51	" " . .	1	..	.25
52	" " . .	4	1	1.25
53	" " . .	2	1	.75
54	" " . .	4	1	1.25
55	" " . .	2	..	.50
56	" " . .	3	..	.75
		159	55	53.5

scribed no albino offspring result. The nature of the resulting offspring is discussed under a separate heading.

In these experiments two black-white males were bred to a number of albino females, and all of the young (forty-three in number) were pigmented. A third black-white mouse, a half-brother to the two just mentioned, was also bred to the same stock of females, and produced pigmented as well as albino young. He, therefore, had the albino character recessive, and was what we have called a hybrid mosaic. All the *pigmented* mice obtained from these three animals bred to albinos are, by formulae (1) and (6), hybrid in respect to the mosaic and the albino characters, and should form gametes one-half of which have the dominant (mosaic) character only, and one-half the albino character only. When these pigmented hybrids are intercrossed, the Mendelian expectation is (formula 2) that 25 per cent of the young will be albinos. The

following table shows by litters the numbers and sorts of young obtained from all the crosses in which the two parents were hybrids between the black-white stock and albinos.

This table shows that out of a total of 214 mice obtained there are actually 55 albinos, where 53.5 are expected. The experimental result is thus closely in accord with the theoretical.

As in the case of the heterozygotes of house-mouse and albino parentage, the relative numbers of pigmented and albino young *in the individual litters* are rarely those demanded by the Mendelian formula. In fact, the precise theoretical ratio obtains in but 7 out of the 56 litters (Nos. 2, 12, 20, 23, 25, 26, 40), where in each case there were three pigmented and one albino young. In two litters (Nos. 25, 26) from ♂ gr. 4 × ♀ gr. 64 this precise proportion was maintained, but a third lot of six young (No. 27) by the same parents consisted wholly of pigmented mice. Cases in which all the young at a birth are albinos are practically wanting in these experiments, being limited to two litters (Nos. 3, 5), where but a single albino represented the entire progeny. Among the 56 litters, however, there is occasionally an excess of albinos over pigmented young, the most notable case, perhaps, being one (No. 6) in which the expected ratio was precisely reversed. There were in this litter 3 albinos to 1 pigmented individual. In all but 9 of the 56 lots of young, there was a greater or less preponderance of pigmented mice, which is a result of the *nature* expected. Two of these 9 litters (Nos. 11, 30) showed an equality of the two classes, the total number of young in each of the two cases being four. In one large litter (No. 28) of 9 young, four were albinos; in another (No. 49) of 8 young, but one was an albino. In the latter case, however, the excess of pigmented mice is but one. It is obvious that in cases where the litter consists of an odd number of individuals, it is impossible in that particular case to obtain a 3 : 1 ratio of the two classes. Hence in a lot of 5 young the nearest approach to the Mendelian ratio is 4 pigmented to 1 albino. In this case there are but .25 too few albino individuals. If two of the five young are albinos, the excess is still represented by less than an integer. Hence the irregularity in distribution of the two characters is a thing to be expected in small litters. In a long series of litters, however, the discrepancies noticed in individual lots tend to counterbalance one another, so that the final result shows a close approximation to the 3 : 1 ratio. This is seen also in cases where a number of young are obtained from *the same pair*. For example, ♂ bl. 342 × ♀ bl. 344 produced two litters, the one (No. 38) of 5 pigmented to 1 albino,

TABLE H.

No.	Parents.	Pigmented Young.	Albinos.	Expected No. of Albinos.	Ratio, Pigmented : Albino.
1	♂ bl.-wh. 1·4 a × ♀ wh. .	..	2	1	18 : 25
2	" " . . .	3	1	2	
3	" " . . .	2	2	2	
4	" " . . .	1	6	3.5	
5	" " . . .	2	5	3.5	
6	" " . . .	3	2	2.5	
7	" " . . .	3	4	3.5	
8	" " . . .	2	2	2	
9	" " . . .	2	1	1.5	
10	♂ bl. 35 × ♀ wh. 34 . . .	4	1	2.5	
11	♂ bl. 60 × ♀ wh. 22 . . .	1	2	1.5	
12	♂ bl. — × ♀ wh. — . . .	4	5	4.5	8 : 7
13	♂ gr. — × ♀ wh. — . . .	4	2	3	
14	♂ wh. 229 × ♀ gr. 105 . .	..	1	.5	2 : 3
15	" " . .	2	2	2	
16	♂ bl.-wh. 240 × ♀ wh. 217 .	1	2	1.5	
17	♂ gold.-ag. 314 × ♀ wh. —	3	4	3.5	7 : 5
18	" " . .	4	1	2.5	
19	♂ bl.-wh. 227 × ♀ wh. 336 .	3	3	3	
20	♂ bl.-wh. 265 × ♀ wh. — .	1	1	1	
21	♂ gold.-ag. 307 × ♀ wh. 141	2	2	2	
22	♂ gr. 40 × ♀ wh. 278. . .	3	2	2.5	5 : 6
23	" " . . .	1	1	1	
24	" " . . .	1	3	2	
25	♂ bl.-wh. 265 × ♀ wh. 121 .	1	1	1	
26	♂ wh. 256 × ♀ gr. 45, 64, 68	1	1	1	
27	♂ gr. 406, 408 × ♀ wh. 281	1	..	.5	
28	♂ ch.-wh. 362 × ♀ wh. 366.	3	2	2.5	
29	♂ wh. 413 × ♀ bl. 416 . .	4	2	3	
30	♂ ch. 274 × ♀ wh. 366 . .	1	1	1	
31	♂ gr. 449 × ♀ wh. 447 . .	3	3	3	
32	♂ ch.-wh. 362 × ♀ wh. 366.	3	2	2.5	
		69	69	69.0	

the other (No. 39) of 4 pigmented to 2 albino mice. Neither litter shows the ideal proportion, but taken together the total result is 9 pigmented to 3 albino mice, the exact Mendelian ratio. Other cases show less close approximation, though the totals for several pairs come within a very small number of the 3 : 1 expectation.

It is clear, then, that these heterozygotes from the spotted stock crossed with albinos tend to produce the two sorts of gametes in equal numbers, so that when intercrossed the ratio of pigmented to albino young is approximately 3 : 1.

Table H gives in condensed form the result of a number of crosses in which an albino was bred to a heterozygote of spotted and albino parentage. In all these cases, the expected result is an equality of the albino and the pigmented classes, by the Mendelian formula (6). In 11 out of 32 litters this expectation is precisely fulfilled. Sixteen of the litters contain an uneven number of young, so that exact equality of the two classes is not possible in the separate lots, though their totals aggregate 38 pigmented to 40 albino mice. The totals for both classes show a very close approximation to the 1 : 1 ratio which the Mendelian law requires. As seen in the other tables, the separate litters of young frequently show a considerable deviation from the 1 : 1 ratio of the two classes. In only two cases (Nos. 1, 14), where the numbers were very small (2 and 1 respectively), were there no pigmented individuals. In ten litters there was an excess of pigmented young, while in ten others the albinos were in excess. The excess in the latter group, however, was usually small, ranging from 0.5 to 1.5 individuals, save in one case (No. 4), a litter of 1 pigmented and 6 albino young, where the latter were 2.5 too many. The discrepancies tend to counterbalance each other as the totals grow larger, so that in the entire lot of 138 individuals there is actual equality. We may, then, conclude that heterozygotes, whether male or female, arising from a cross between a pied and an albino stock, tend to produce in equal numbers gametes representing the pigmented and unpigmented conditions.

An account of the writer's experiments on the heredity of complete albinism having been given in what precedes, a review is now added of experiments along similar lines recorded by others.

Crampe ('77) gives the partial results of certain crosses with rats, and in a later, more elaborate paper ('85) gives a summary of his crosses for a period of some ten years. This latter paper, though containing an immense accumulation of data, is unfortunately so obscure in many places as to cause considerable uncertainty as to what sorts of animals were used in the various crosses. It seems clear that in many cases three stocks, a

wild, a pied, and an albino, were interbred, whereas in other cases only two of these stocks were kept together. After a long study of Crampe's tables, the writer has been able to extract from them a number of cases in which it is evident that both parents concerned were pied or mosaic animals having the albino character recessive, as evidenced by the presence of albinos among their young. Crampe seems to have kept some of his rats together in "families," by which term he refers to certain lots. Others seem to have been single pairs. The following Table (I) shows in condensed form the results of these crosses. Other crosses, by which albinos were produced, are considered under a separate head, as the families appear to have had three characters among them, instead of the two here treated.

TABLE I.

No.	Color of Parents.	Gray-white Young.	Black-white Young.	Albinos.	Expected No. of Albinos.	Excess of Albinos = +. Shortage of Albinos = −.
1	♂ bl.-wh. × ♀ bl.-wh.	..	..	2	.5	+1.5
2	" "	..	4	2	1.5	+ .5
3	" "	..	12	1	3.25	−2.25
4	" "	..	6	2	2	±
5	" "	..	6	1	1.75	− .75
6	" "	..	17	6	5.75	+ .25
7	♂ gr.-wh. × ♀ gr.-wh.	19	8	5	8	−3
8	" "	16	5	12	8.25	+3.75
9	" "	8	9	4	5.25	−1.25
10	" "	8	4	6	4.5	+1.5
11	" "	24	5	7	9	−2
12	" "	13	..	3	4	−1
		88	76	51	53.75	−2.75

In these crosses, it is plain that the numbers of young given for the respective pairs represent in some cases the totals of successive litters, while in others they indicate single litters. In each case, however, the theoretical number of albinos is very nearly realized, and although there

is exact agreement in but one case (No. 4), the shortage or excess in any one lot was not over 3.75, and this (excess) occurred in but a single case (No. 8). Moreover, as previously pointed out, an exact 3 : 1 ratio of pigmented to albino mice is rarely to be expected experimentally, and even then only in lots where the number of young is 4 or a multiple of 4. Hence, it is only " in the long run " that the theoretical ratio may be expected to obtain closely. The totals in this case are 164 pigmented to 51 albino rats (or 23.5 per cent albinos), so that the latter class is but 2.75 individuals, or 1.5 per cent, short of the expected total. The irregularities in respect to the numbers of albinos are very evenly divided among the eleven lots in which the 3 : 1 ratio was not realized. For in five lots (Nos. 1, 2, 6, 8, 10), there was an excess of albinos ranging from 0.25 to 3.75 individuals, with a total of 7.5, as against six lots (Nos. 3, 5, 7, 9, 11, 12), showing a shortage in the number of albinos, ranging from 0.75 to 3 individuals, or a total of 10.25 individuals. Crampe's rats therefore show that complete albinism is inherited among them precisely after the Mendelian principles, though with small numbers the exact Mendelian ratio may not be closely approximated. No extended series of crosses in which the ratio of pigmented to albino young is expected to be as 1 : 1 is given by Crampe.

In two noteworthy communications von Guaita ('98, : 00) gives his results in breeding black-white dancing mice to albinos of an inbred stock. His experiments were performed manifestly without reference to the Mendelian principles, but nevertheless when the results are examined, they afford additional proof in support of those principles.

Castle (: 03[d], p. 226) has already shown that as regards the numbers of pigmented and albino young obtained by von Guaita there is almost perfect accord with the total expected on the Mendelian hypothesis that the two characters undergo segregation. The following table (J) is a slight expansion of the one that Castle has constructed, and shows the numbers of albinos expected and those actually obtained, as well as the numbers of pigmented mice. In some cases, the total number of young obtained from a single pair of mice is not sufficient to show conclusively whether or not either of the parents had the albino character recessive, and for these cases an allowance has to be made; yet their effect on the total result is insignificant. The Mendelian formula applicable to each case is indicated by the figures in parenthesis in the proper column.

As regards the inheritance of complete albinism, it is seen that from the various crosses, producing in all 309 mice, a total of 77 albinos occurred, where the expectation was that there should be from 75 to 79.

TABLE J.

(Based on Observations of von Guaita.)

Serial No.	Generation.	Pair.	Gray Young.	Black Young.	Gray-white Young.	Black-white Young.	Albinos.	Expected No of Albinos.	Expected Per cent of Albinos.	Mendelian formula applicable.
1	F_1	..	28	..	..	..	..	0	0	(1)
2	F_2	1	5	..	3	1	4	3.25	25	(2)
3	"	2	7	2	4	..	6	4.75	25	(2)
4	"	3	2	..	2	..	..	1	25	(2)
5	"	4	2	2	..	..	4	2	25	(2)
6	F_3	1	..	..	..	..	4	4	100	(4)
7	"	2	13	..	3	..	..	0	..	(1)
8	"	3	..	..	2	..	..	0 or .5	0 or 25	(3, 2, 5)
9	"	4	2	4	..	1	..	0	0	(1)
10	"	5	1	..	..	..	1	1	50	(6)
11	F_4	1	..	..	16	..	..	0	0	(3, 5)
12	"	2	..	..	..	..	..	..	..	eaten.
13	"	3	..	1	..	2	2	1.25	25	(2)
14	"	4	..	10	..	15	7	8	25	(2)
15	"	5	1	1	4	7	..	0	0	(3, 5)
16	"	6	..	..	35	..	9	11	25	(2)
17	"	7	2	..	..	..	1	.75	25	(2)
18	F_5	1	1	..	21	..	10	8	25	(2)
19	"	2	..	..	..	..	6	6	100	(4)
20	"	3	..	7	..	16	20	21.5	50	(6)
21	"	4	..	1	..	1	..	0 or .5	0 or 25	(3, 2, 5)
22	"	5	1	1	1	..	..	0 or .5	0 or 25	(3, 2, 5)
23	F_6	1	..	..	4	..	..	0 or 2	0 or 50	(1, 6)
24	"	2	..	..	..	..	..	..	..	eaten.
25	"	3	..	..	..	..	3	3	100	(4)
			65	29	95	43	77	75–79		

This range of 4 individuals in the theoretical total is due to the fact that in three, or possibly four, cases the litters were so small that they did not show conclusively whether or not the parents were producing gametes having the albino character. For it is obvious that where both parents are pigmented, the expectation is but one albino in four young, provided both parents have the albino character recessive, hence where less than four young are obtained, and no albinos are among them, it cannot be told, *from this test alone*, whether one or both of the parents produce the two sorts of gametes. For if *one* parent produces only gametes having the pigment character, no albino young will result even though the other parent produces the two sorts of gametes (formula 5). The three cases of this sort among von Guaita's crosses (Nos. 8, 21, 22) necessitate making a possible allowance of from .5 to 1.5 individuals in the theoretical total. Another litter (No. 23) for which allowance may be made is one the parents of which were a spotted and an albino mouse. Had the former contained the albino character in a recessive condition, the theoretical result would have been 50 per cent of pigmented and 50 per cent of albino individuals. To be sure, all of the four young resulting from the cross are pigmented, yet in the tables previously given one sees that it is possible to obtain in a single litter, from a cross of this sort, four pigmented individuals with *no* albinos. Hence, if the greatest possible allowance be made, the actual result is but 2 individuals short of the theoretical, while the most favorable allowance would give an exact agreement.

It may be well to explain in brief the methods by which the above conclusions as to the expected proportions of albinos were reached, and also to analyze the results still further. Generation P (the original parents crossed — Bateson) consisted entirely of crosses in which the one parent (the spotted mouse) possessed only the dominant character and the other (the albino mouse) only the recessive character. In all cases, therefore, by formula (1), heterozygotes are produced, and no albinos. The second generation (F_2) was obtained by interbreeding these heterozygotes (F_1). Assuming that segregation of pigment and albino characters takes place in accordance with Mendel's law, it is expected (by formula 2) that 25 per cent of the resulting offspring will be albinos. The fours pairs of heterozygotes (Nos. 2–5) did actually produce albinos except in one case (No. 4), where but four young were born. In a total of 44 individuals of this generation there were actually 14 albinos, an excess of 3 over the theoretical number. Generation F_3 consists of the young of five pairs selected from the preceding generation. The first of these pairs was of two albinos, and only albino young resulted.

The second, fourth, and fifth pairs consisted each of a pigmented and an albino mouse. The only circumstance under which albinos might result from these three pairs is that the spotted parent should have the albino character recessive, when 50 per cent of the resulting offspring should be albinos. Two of these pairs produced, in a total of 16 and 7 young respectively, no albino young, hence it is safe to assume that the pigmented parents were in each case pure, as regards the albino character, and the result falls under formula (1). In the case of pair 5, however, the pigmented parent evidently did contain albinism in a recessive condition, and the litter of *two* young shows the Mendelian equality demanded by formula (6). The third pair consisted of two spotted mice. There are here three possibilities. (1) Both parents may contain albinism recessive, in which case 25 per cent of the young produced should be albinos; (2) only one parent or (3) neither parent may contain that character, so that *no* albinos could occur (by formulae 5 and 3). Since but two offspring were obtained, it cannot be certainly told which expectation is the correct one, for at least four young are theoretically necessary in order that the albino class may be actually present in the proportion of 1 albino to 3 pigmented mice. Generation F_4 was produced by seven pairs, though only six of these contributed to the record given. In each of the six cases, the two parents were pigmented animals, so that (as in the third pair of F_3) three possible unions are represented. In case albinos are produced by any pigmented pair, it is evident, on Mendelian principles, that both parents are producing gametes with the albino character as well as those with the pigment character. Four of the six pairs which form this generation are of this sort, hence, both parents being heterozygotes, 25 per cent of their offspring are expected to be albinos (formula 2). These four pairs produced 84 young, of which 19 were albinos, that is, the albino class shows a shortage of but 2 individuals, or about 2 per cent. In case of the two remaining pairs, only pigmented young were obtained, 16 and 13 respectively. Had all the four parents contained albinism recessive, there would have been expected 4 and 3 albinos respectively among the offspring of the two pairs. Since no albinos occurred among the totals, it is safe to assume that at least one parent of each pair was pure with respect to the character albinism. Possibly both parents in each case were pure in this respect, but the result is the same in so far as the production of albinos is concerned, for none are expected in either event.

Generation F_5 results from the interbreeding of five pairs of mice from generation F_4. Both animals of the first, fourth, and fifth pairs were pig-

mented, hence in order that the albino class shall be represented in their progeny it is necessary that both mice of each of the three pairs shall be heterozygotes, having the albino character recessive. This condition evidently obtained in case of pair 1, for out of a total of 32 young, 10 were albinos, where but 8 were expected. Neither of the two other pairs produced albinos, but their totals are too small to show conclusively the nature of the parents, the one pair having but two, the other three young. Pair 2 of this generation consisted of two albinos, and as expected, all their young were of that class. Pair 3 consisted of a spotted and an albino mouse. The former evidently had the albino character recessive, for the result of the cross with the albino mate was to produce 23 pigmented and 20 albino mice. This result is less than two individuals short of the expected equality of the albino and the pigmented classes.

Finally, for generation F_6 there are three litters, one of which was destroyed before its character could be determined. Of the remaining two litters, one consists of 3 albinos from albino parents, the expected result. The other pair is of a spotted and an albino mouse. In this case no albinos are expected provided the spotted parent is pure as regards the albino character. As a matter of fact, none of the four young obtained was an albino. Nevertheless it is within the limits of possibility, as the writer's experiments have shown, to obtain no albinos in a litter of four, even when 50 per cent of the young are expected to be of this sort. Hence it is necessary to make allowance for the possibility that the spotted parent may have been a heterozygote containing the albino character recessive.

The crosses made by von Guaita, as far as they throw light on the heredity of complete albinism, may be summed up as follows: (1) In all cases wherein pure pigmented (spotted) animals were mated with albinos the pigmented character of the former proved dominant over total albinism. (2) Unions of two albinos resulted in the production of albino offspring only. (3) In cases where both parents were proved to be heterozygous with respect to the two characters of coat color, 43 albinos to 117 pigmented mice were produced, the albinos being thus 3 individuals, or less than 2 per cent, in excess of the theoretical number. If the three indeterminable cases be added, the number of albinos is but one individual less than that expected. (4) In cases where it is expected that the two classes shall be as 1 : 1, this ratio is very closely approximated, the totals being 24 pigmented : 20 albino mice. It is clear, then, that von Guaita's mice behaved according to the Mendelian expectation, and as far as known to the writer, his experiments are the earliest pub-

TABLE K.

(Based on observations of Parsons and Copeman.)

No. of Exp.	Parents.	Black.	Black-white.	Brown.	Brown-white.	Albinos.	Expected No. of Albinos.	
26	♂ bl.-wh. × ♀ br.-wh.	..	..	..	1	1	.5	+ .5
27	" "	..	2	..	2	2	1.5	+ .5
32	♂ bl.-wh. × ♀ bl.	5	..	..	..	2	1.75	+ .25
33	" "	7	1	..	..	..	2	−2
34	" "	2	2	1	..	..	1.25	−1.25
37	♂ br.-wh. × ♀ br.	2	..	1	..	3	1 5	+1.5
38	" "	..	..	3	2	3	2	+1
42	♂ bl.-wh. × ♀ bl.-wh.	..	7	..	..	..	1.75	−1.75
43	" "	..	4	..	..	2	1.5	+ .5
44	♂ br.-wh. × ♀ bl.-wh.	..	7	..	..	1	2	−1
		16	23	5	5	14	15.75	

lished from which it is possible to obtain statistical proof of the validity of Mendel's laws among mice.

In three recent papers, Darbishire (:**02**, :**03**, :**03**[a]) has summarized certain of his results in crossing spotted "fawn-white" Japanese waltzing mice with albino mice, and these observations, too, confirm the law of segregation, in that the crosses show complete albinism to be inherited in the proper Mendelian proportions. In the first cross of the two stocks, only heterozygotes resulted in accordance with formula (1). In his second paper (:**03**) the results of intercrossing these heterozygotes are given, and it is stated that in a total of 66 young, 13 are albinos, where 16.5 are expected; 225 young are obtained by back-crossing heterozygotes with albinos, and of these 119 are albinos, the expectation being 112.5. The total number of albinos is thus 132, where the expectation is 129. Hence a fairly close agreement is shown. This author's final report is awaited with interest, and is expected to shed further light on questions of Mendelian inheritance.

Finally, Bateson (:**03**[b]), in a discussion of color heredity among rats and mice, adduces 50 matings of mice, contributed by Mr. F. J. Parsons

in conjunction with Dr. S. M. Copeman. In Table K are summarized the cases in which both parents were heterozygotes and produced both pigmented and albino young.

These results are quite similar to those previously reviewed. In a total of 63 mice, the albinos appear in practically their calculated proportion, being 14 in number instead of 15.75, which is as close an agreement as might reasonably be demanded. In six of the ten litters, the albinos are in excess, the total excess being 4.25 individuals, yet this is more than offset by the shortage in the four remaining litters, amounting to 6 individuals. In one case, no albinos occurred in a litter of 8, and again none in a lot of 7 young. In other cases the two classes, pigmented and albino, occurred in equal numbers in separate litters, though in none did the albinos outnumber the pigmented mice. In 21 cases, albino mice were bred to heterozygous individuals, so that 50 per cent of the offspring are expected to be albinos. The following table (L) shows the results of these matings.

As pointed out by Bateson, the expected equality of the pigmented and the albino classes is here realized. One black-white male bred to several albino females produced in all 27 pigmented to 31 albino young; and a brown-white male under similar circumstances produced 11 pigmented to 19 albino mice. In these two cases the 1 : 1 ratio is rather closely approximated. On the other hand, four heterozygous females, bred to albino males, give 16 pigmented and 7 albino young, which Bateson believes can hardly be a fortuitous departure from the expected equality. Yet the departure is actually but 4 or 5 individuals, and may be entirely a matter of chance. For even the black-white male, previously mentioned as producing a very nearly equal number of the two sorts of gametes, at one time fathered a litter consisting of 5 albinos by an albino female. Indeed, the record of this male shows that although in the long run the two sorts of gametes are produced in relatively equal numbers, yet, as pointed out in other cases, separate litters show that there is considerable variation in the proportions of the two sorts of gametes which are fertilized at each mating.

To sum up, it would seem to be conclusively proved that among house mice, fancy mice, and rats, complete albinism is inherited strictly in accordance with the Mendelian principles. Investigations have up to this time shown no clear cases of deviation from the common 3 : 1 and 1 : 1 ratios of pigmented to albino individuals when any considerable number of offspring is taken into consideration.

(3) *Complete albinism and two other coat characters.* In the cases

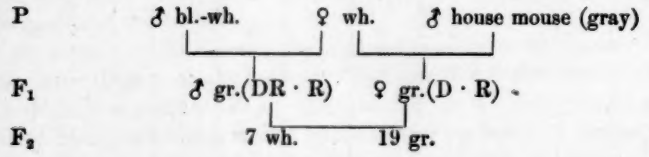
TABLE L.

(Based on observations of Parsons and Copeman.)

No. of Exp.	Parents.	Black.	Black-white.	Brown.	Brown-white.	Albinos.	Expected No. of Albinos.
1	♂ bl.-wh. × ♀ wh.	..	1	..	..	3	2
3	♂ br.-wh. × ♀ wh.	..	..	..	1	3	2
4	♂ bl.-wh. × ♀ wh.	..	2	..	1	4	3.5
6	♂ br.-wh. × ♀ wh.	..	..	..	..	5	2.5
7	" "	..	..	..	4	1	2.5
10	♂ bl.-wh. × ♀ wh.	2	..	1	..	1	2
12	♂ br.-wh. × ♀ wh.	..	..	2	..	6	4
13	" "	2	..	2	..	4	4
14	♂ bl.-wh. × ♀ wh.	3	..	1	..	2	3
15	" "	..	2	..	2	4	4
16	" "	..	1	..	1	2	2
18	" "	..	2	..	..	3	2.5
19	" "	..	2	..	..	1	1.5
21	" "	..	4	..	..	3	3.5
23	" "	..	5	..	..	2	3.5
28	♂ wh. × ♀ br.-wh.	..	1	..	4	1	3
35	♂ wh. × ♀ bl.	1	3	1	..	2	3.5
39	♂ wh. × ♀ br.	1	1	..	1	2	2.5
40	♂ bl.-wh. × ♀ wh.	..	2	..	..	3	2.5
41	" "	..	..	..	..	5	2.5
47	♂ wh. × ♀ bl.	1	2	..	..	2	2.5
		10	28	7	14	59	59.0

thus far considered the heredity of complete albinism has been studied with respect to its behavior when brought into association with either total pigmentation or partial pigmentation. It has been shown that, when

the wild house mouse or the wild brown rat is crossed with an albino, heterozygotes are produced in which the character, total pigmentation, is dominant, and complete albinism is recessive. In the case of the spotted varieties of mice and rats it is also found that the pigmented condition is dominant over complete albinism. In both cases the heterozygotes produce, on interbreeding, the Mendelian proportions of pigmented and of albino individuals. This is true, furthermore, where two heterozygotes are mated, of which the one had a wild totally pigmented mouse as the colored parent, and the other a spotted or partially pigmented one. To illustrate: the writer bred house mice to albinos and obtained gray heterozygotes. Black-white mice were also bred to the same stock of albinos, and gray heterozygotes were obtained similar in outward appearance to those from the other cross. The following diagram shows this parentage:



The heterozygotes of generation F_1 were then interbred, and as each contained complete albinism recessive, it is expected that 25 per cent of the young of generation F_2 would be albinos. The actual result was that, of 26 young produced, 19 were gray, and 7 were albinos. The albinos are thus but .5 of an individual in excess, so that, within the possibilities of experimentation, the expectation is realized. Some of the pigmented mice showed small flecks of white on tail and feet, but unfortunately no exact record of this was kept.

A different result is to be expected on Mendelian principles, if, instead of *both* animals of generation F_1 having complete albinism recessive, only *one* is of this nature. If we postulate that the other parent shall be a homozygote, two conditions are now possible which will allow the occurrence of three coat characters in generation F_2: either (1) the heterozygote must produce gametes representing respectively the *spotted* and the *albino* conditions, while the homozygote's germ cells contain only the character total pigmentation; or (2) the gametes of the heterozygote must represent in equal numbers the characters total pigmentation and albinism, while those of the homozygote represent only the spotted character. If matings such as these be made, the offspring will be of two sorts, *half* of

them having complete albinism recessive, while the other half are heterozygous with respect to total and partial pigmentation. If these young be now intercrossed in all possible ways, the final result will be that only 1 in 16 individuals will be albino, instead of 1 in 4. To make this more clear, the two possible cases are worked out below, D representing the dominant condition of total pigmentation as seen in the wild house mouse or rat; DR, the mosaic or spotted condition in which albinism occurs in the soma between pigmented patches; and R representing the albino condition. A period between two of these signs used together shows that segregation takes place at that point and the resulting gametes are of the nature expressed by the symbols on the right and the left of the period respectively.

Case I.

Heterozygote = DR·R; homozygote = D·D. This mating gives the following result:

$$\begin{array}{rl} DR + R & = \text{gametes of heterozygote,} \\ D + D & = \text{“ “ homozygote,} \\ \hline 2D{\cdot}DR + 2D{\cdot}R & = \text{offspring, or generation } F_1. \end{array}$$

If, now, these F_1 animals be allowed to breed *inter se*, three combinations (*a.*, *b.*, *c.*) are possible, and the smallest number of individuals representing all the possible unions in their probable proportions is 16, thus:

a.

Parents both D·DR

$$\begin{array}{r} D + DR \\ D + DR \\ \hline D + 2D{\cdot}DR + DR \end{array}$$

b.

Parents both D·R

$$\begin{array}{r} D + R \\ D + R \\ \hline D + 2D{\cdot}R + R \end{array}$$

c.

Parents one D·DR, the other D·R

$$\begin{array}{r} D + DR \\ D + R \\ \hline 2(D + D{\cdot}DR + D{\cdot}R + DR{\cdot}R) \end{array}$$

There is one chance each for mating *a* and *b*, where there are two chances for mating *c*. If all these unions take place in their chance frequencies, there will result six sorts of animals as follows:

$$4D + 1DR + 4D{\cdot}DR + 4D{\cdot}R + 2DR{\cdot}R + 1R.$$

Of the 16 individuals, 9 (or those of the first three classes just enumerated) do not have albinism recessive; 6 (or the next two classes) do have that character recessive, while the 16th animal is a pure recessive.

Case II.

Here the heterozygote is D·R, and the homozygote is DR. The result is the same as in Case I, save that there is a slightly different proportion of certain of the pigmented classes, as may be seen from the following:

$$\begin{array}{rl} D + R & = \text{gametes of heterozygote,} \\ DR + DR & = \text{“ “ homozygote,} \\ \hline 2D{\cdot}DR + 2DR{\cdot}R & = \text{offspring, or generation } F_1. \end{array}$$

The possible unions among the animals of generation F_1 are:

a.

$$\begin{array}{r} D + DR \\ D + DR \\ \hline D + 2D{\cdot}DR + DR \end{array}$$

b.

$$\begin{array}{r} DR + R \\ DR + R \\ \hline DR + 2DR{\cdot}R + R \end{array}$$

c.

$$\begin{array}{r} D + DR \\ DR + R \\ \hline 2(D{\cdot}DR + DR + D{\cdot}R + DR{\cdot}R) \end{array}$$

Total of F_2:

$$1D + 4DR + 4D{\cdot}DR + 2D{\cdot}R + 4DR{\cdot}R + 1R.$$

The writer has not been able fully to test experimentally the relations here worked out, to see if they actually occur under proper crossing. In one instance, however, a chocolate-white male, a pure DR, was bred to a gray heterozygote whose parents were a house mouse and an albino. This mating is therefore of the sort explained under Case II, above. Two litters were obtained from this pair, the one of 5, the other of 6 young. All these 11 young were gray. The individuals of the second litter were allowed to grow up and breed together, in order that they might show, if possible, what result would come of their random mating. When about five months old these six heterozygotes produced two lots of young. The first lot consisted of a chocolate and an albino mouse;

the second was of 6 entirely gray mice. Referring again to the example given under Case II, it is seen that the six gray mice of generation F_1 are theoretically of two sorts, D·DR and DR·R. The only union by which albinos could be obtained from these parents is that of two DR·R individuals. That it *was* this union which produced the litter of 1 chocolate and 1 albino, seems to be additionally proved by the occurrence of the chocolate individual. No case is as yet recorded in which the house mouse in the second generation from a cross with albinos has produced chocolate young, hence it is more than likely that the young one of this color inherited that character directly from the chocolate-white grandfather; that is, either two DR gametes or a DR and an R gamete united to produce it, so that its parents were both of the DR·R class. The fact that there were no albinos among the 6 individuals of the second litter probably indicates that the parents were in this case either two D·DR individuals or a D·DR and a DR·R., neither of which combinations would result in the production of albino offspring.

As a means of testing the relations of the three characters involved in a case of this sort, some of the statistics given by Crampe ('85) appear to be applicable. This investigator details a number of litters obtained by inbreeding the members of a single family, wherein there is evidence that the three characters, which have just been considered, were present. Thus on page 604 he gives a table containing the results of inbreeding derivatives of "species" by albino (Compare Table M). Since there occur numerous spotted young in the progeny, it is hardly to be doubted that what Crampe thought was the "species" was really a heterozygous (D·DR) individual containing both the character total pigmentation and that of partial pigmentation. This interpretation is rendered still more probable by the fact that these animals were of "variety 6," *i. e.* black with traces of white on toes or tail, a condition which is often seen in mice from wholly pigmented and spotted parents. Another table of the same kind (see Table N) is given on p. 603 of the "Farben-Inzucht, Farben-Reinzucht und Farbenkreuzung" in Family H. This family also had the three characters D, DR, and R, represented among its members, as the table of ancestry shows, for albinos, "species," and spotted animals are hopelessly intermingled. A third table, on p. 612 (see Table O), furnishes additional data of the same sort, where gray-whites are inbred from a cross of "species" with a heterozygous black-white rat (DR·R). The exact nature of all the matings cannot be known, but it appears that "families" of rats in many cases, at least, were kept together, so that there was every chance for random mating, and the totals given may

represent in some cases a number of litters from various parents. These three tables may now be examined with a view to observing whether or not complete albinism is present in one in sixteen of the offspring, as is expected.

By way of explanation it may be stated that Crampe used abbreviations for denoting the colors of his rats. Thus, in the tables which follow, "var. 5" denotes a black-white rat, "var. 6" is a black animal with small flecks of white, usually confined to the feet, forehead, middle of belly, and tip of tail, and "var. 7" is wholly black.

TABLE M.

(Based on observations of Crampe.)

	Male Parent.	Female Parent.	Black-white Young.	Black with White Flecks.	Black.	Albino.
1	var. 6	var. 6	..	8	1	..
2	"	"	5	4	1	..
3	"	"	5	5	2	..
4	"	"	1	4	1	..
5	"	var. 7	..	10	6	..
6	"	"	..	7	4	..
7	"	"	..	2	3	2
8	"	var. 6	3	9	2	1
9	"	"	2	5	2	2
10	var. 7	var. 7	..	6	26	..
11	"	var. 6	..	17	10	3
12	var. 6	"	5	6	..	2
13	"	"	6	13	..	6
14	var. 7	var. 7	..	7	8	..
15	"	"	..	1	10	2
16	var. 6	var. 6	15	15	5	..
17	var. 7	var. 7	..	..	13	..
			42	119	94	18

In a total of 273 rats, it is expected that $17\frac{1}{16}$ will be albinos, and there are actually 18. It is evident that albinos can result from any one of three matings, DR·R × DR·R, D·R × D·R, or DR·R × D·R, and in each case the albinos are to the pigmented rats as 1 : 3. In cases 7, 9, 12, 13, and 15 this ratio obtained, but in cases 8 and 11 the albinos are more nearly as 1 : 16, and it is not improbable that the totals in the two latter cases represent the results obtained where entire families containing two sorts of heterozygotes were bred *inter se*.

Table N is reproduced from the data given by Crampe ('85) on page 604.

TABLE N.

(Based on observations of Crampe.)

	Male Parent.	Female Parent.	Black-white Young.	Black with White Flecks	Black.	Albino.
1	var. 6	var. 6	3	10	..	
2	"	var. 7	..	7	7	
3	"	"	..	1	4	
4	"	var. 6	11	18	4	3
5	"species" ×	gr.-wh. 2d. gen.	6	28	12	4
6	"	"	14	32	..	2
			34	96	27	9

This lot gives a total of 166 young, and 9 are albinos where $10\frac{3}{8}$ are expected. If the matings represented by this table are those given under our "Case II," we expect that $\frac{3}{16}$ or 31 of the animals produced will be unspotted (i. e. of classes D and D·R), and there are actually 27 entirely black. It is impossible to say which of the remaining individuals belong to the DR, D·DR, or DR·R classes, since these combinations may give a varying amount of spottedness.

The last of Crampe's ('85) tables to be considered (Table O) is that given by him on page 612, which contains the totals obtained by inbreeding, for five generations, families of gray-white rats among which were

the three characters D, DR, and R, as appears from Crampe's statement. The young of "family K" are also included, being of a similar nature.

TABLE O.

(Based on observations of Crampe.)

Generation.	"Family."	Gray-white Young.	Black-white Young.	Albinos.	Expected No. of Albinos.
3	P 230	59	..	5	4
4	P 330	59	..	2	$3\frac{1}{16}$
5	P 430	33	..	2	$2\frac{3}{16}$
6	P 530	20	..	3	$1\frac{7}{16}$
7	P 630	41	..	2	$2\frac{11}{16}$
..	K 20	19	2	2	$1\frac{5}{16}$
		231	2	16	$15\frac{7}{16}$

This table is particularly instructive because it is certain that the total for each generation represents the sum total of all the unions that took place among the various heterozygotes of a single family. The closeness with which the numbers of albinos obtained approximate the theoretical $\frac{1}{16}$ is certainly remarkable.

It will be noticed also that this table contains no class showing total pigmentation, — a fact which may mean a partial change of the D character through long inbreeding and association with the characters DR and R. The degree of white marking among the gray-whites is of course very variable, and it is assumed that in the present instance gray rats showing only a few flecks of white were included with the rest, though probably resulting from a cross of wild gray and either partial or total albinism. For Crampe states that the latter cross did sometimes give gray individuals with whitish feet or white tips of tail. This fact is referred to in the discussion of partial albinism.

To sum up the results of the three tables, we have, by the interbreeding of heterozygotes, among which three allelomorphic characters are

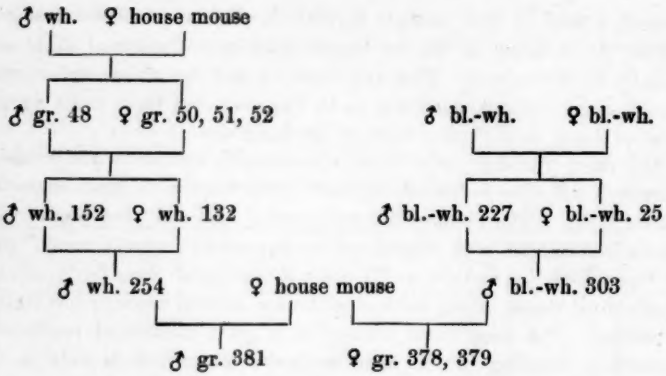
present, a total of 688 young. By the Mendelian principle of segregation, $\frac{1}{16}$ of these, or 43, are expected to be albinos, and there are actually 43 of this sort. That the observed and the theoretical results should closely approximate was to be expected, but their exact agreement to a unit is, of course, more or less fortuitous.

Still other combinations of three allelomorphic characters are possible. Bateson (: 03[a]) has indicated one such with respect to comb character among fowls. The characters "rose comb" (R) and "pea comb" (P) are each dominant with respect to the character "smooth comb" (S). A "pea comb" is defined as "a comb consisting of three fairly regular longitudinal ridges, along each of which are several more or less lumpy tubercles." "A rose comb consists of a great number of papilliform elevations, standing in the same horizontal plane. It is wide in the middle, and contracts to a point or 'pike' behind." Two heterozygotes, the one by parents having respectively pea comb and smooth or single comb, the other by parents having respectively rose comb and smooth comb, were bred together. The two heterozygotes thus had each a different dominant comb character, though both had the same recessive character. The result of their union was the production of four sorts of young. The following scheme shows the nature of the unions:

$$\begin{aligned} R + S &= \text{gametes of rose (smooth) fowl,} \\ P + S &= \text{“ pea (smooth) “ ,} \\ \hline F\,2:\ RP + PS + RS + SS &= \text{possible unions.} \end{aligned}$$

These four classes were found to be actually present in F_2, each well characterized. The RP combination was peculiar, resembling the "walnut" comb of some Malayan fowls. In generation F_3, the results of which are not fully published as yet, Bateson found evidence of imperfect segregation in some of the RP class.

A series of somewhat similar experiments has been made by the writer, using mice. The character common to both heterozygotes was that of total pigmentation, derived from a cross with the wild gray house mouse. The other two characters were in the one case complete albinism, and in the other partial albinism, the latter from a black-white male known to be pure with respect to that character. The following scheme will serve to show the derivation of the two sorts of heterozygotes used:



From the union of these two sorts of heterozygotes (♂ gr. 381 and ♀ gr. 378, 379) there were obtained thirteen young, of which nine were entirely gray and four were gray with small white flecks on the forehead, tail, or belly, one having also white feet. According to the Mendelian principles of segregation, the unions taking place to produce these thirteen young are the following (using the letters D, DR, and R as before, to express respectively total, partial, and no pigmentation) :

$$\begin{array}{l} D + R \;\; = \text{gametes of } ♂, \\ D + DR = \;\; “ \;\;\;\;\; ♀, \\ \hline D + D{\cdot}R + D{\cdot}DR + DR{\cdot}R = \text{offspring} \end{array}$$

No albinos should result in F_1, nor were there any produced. It now became necessary to test the individuals of this generation severally in order to determine their nature. As previously stated, four of the young had small flecks of white on their otherwise gray coats. One of these slightly spotted mice was bred to an albino of spotted ancestry (the importance of this latter fact is elsewhere pointed out), and six young were produced, three of which were gray with white spots, and three were albinos. Evidently, then, the pigmented animal being tested was either of the class DR·R, or D·R, these being the only two in which complete albinism was present as a recessive allelomorph. That it was actually of the class DR·R, however, is sufficiently shown from the fact that it not only showed partial albinism in the soma, but its three spotted young by the albino showed a still greater amount of white. It

is interesting further to note the exact 1 : 1 ratio of the two classes, pigmented and completely albino young, in this litter of six. A second individual was tested in like manner. This time a gray mouse, showing no trace of white in the pelage, was chosen, and bred to an albino of spotted ancestry. Of the four young resulting, two were entirely gray and two were spotted, the one being gray-white, the other black-white. It is plain that in this case the gray parent was of the class D·DR. For the possible unions of such an animal with the albino would result in two animals of the character D·R (here presumably represented by the two all-gray young) and two of the character DR·R (the two spotted individuals). Moreover, these two sorts of young are actually present in the ratio 1 : 1 as expected.

It is interesting to observe that of the four possible classes of young by the heterozygous parents, viz.: D, D·DR, D·R, and DR·R, only one, the class DR·R, is expected to show a spotted coat. In the thirteen young obtained representing these four classes, we therefore look for three, or one-fourth the total number, to be spotted, and there are actually four. It is unsafe, however, to assume that all these spotted young are of the class DR·R, for a mouse of the class D·DR may sometimes show white flecks on the tail. The case appears to be an instructive one, however, and so far as worked out, conforms to the Mendelian laws. No attempt has been made to interbreed at random the four sorts of individuals of F_1 which have been considered, viz.: D, D·R, D·DR, and DR·R. It may readily be calculated, however, that if all the possible unions were to take place, the smallest total number of individuals representing all such combinations would be sixty-four. The same six classes as previously worked out would be present, and the total albinos would still be one in sixteen. The relations of these classes to one another would be: 16 D: 16 D·DR: 16 D·R: 4 DR: 8 DR·R: 4 R. It may be seen that an actual statistical test of a case of this sort is far from being a simple matter.

4. *Albinos bred inter se.* So far as certainly known, two albinos when interbred produce only albinos, or, as is commonly said, albinos breed true. It must not be assumed, however, as some recent writers have done, that any given albino is the exact equivalent of any other albino, in so far as concerns its influence in the heredity of characters other than albinism. The writer has obtained a large number of young both from interbreeding mice of albino parentage and from interbreeding those which Bateson has termed "extracted recessives," that is, the young of two pigmented heterozygotes which each contain the albino

character recessive. No union of two albino mice, regardless of their parentage, has ever given any but albino young in the present writer's experience. This result is corroborated by the observations of a number of other investigators. Thus, von Guaita ('98; :00), Cuénot (:02), and Bateson (:03[b]) record crosses of two albino mice in which only albino young were produced. Crampe ('85) obtained a similar result in his experiments with albino rats. In the case of other mammals, also, a like result has been obtained. Both Cumberland (:01), and Castle and Allen (:03) state that albino guinea pigs breed true to that character, and Woods (:03) has made a similar record in the case of albino rabbits of colored parentage.

In man it has been shown that complete albinism is a recessive character (see Farabee, :03, and Castle, :03[a]; also Bateson, :03[b]), and it is to be expected that two human albinos would have albino children only. The two authors last mentioned, however, have shown that in the negro a marriage of pigmented and albino persons has resulted in the production of pigmented children only, and in the case of a marriage of two other normally colored persons (one being a known heterozygote) albino as well as pigmented children were born. Mr. A. H. Clark, in a letter to the writer, makes the interesting observation that in a case which came to his notice while in the West Indies, an albino negress gave birth to only normally pigmented children, her husband being a normal negro.

A further illustration of the recessive nature of the albino character is recorded by Mlle. Barthelet (:00). This observer made three series of experiments with gray house mice and albinos, for the purpose of testing the supposed phenomenon of telegony. In the first series, four virgin albinos were covered by as many gray house mice. In each case only gray young resulted. Each female was then bred to an albino, and only albinos resulted. In the second series of experiments, a white female that had never borne young, was bred to a gray house mouse for three successive times, and produced only gray young. Being then covered by an albino male, she gave birth to albinos only. In the third series of experiments, a similar albino female was bred alternately to an albino and to a gray male, with the result that by the albino male only albino young were produced, and by the gray male only gray young. Some such result as this in other cases may have been the foundation for J. von Fischer's ('69) erroneous statement that in crosses between a normal and an albino form the young are like the male parent. Mlle. Barthelet's results might have been precisely predicted by one acquainted with the Mendelian principles of heredity. The work was apparently per-

formed without a knowledge of these laws, which were then in process of rediscovery; but it shows clearly that a previous cross with a pigmented animal will not in any way interfere with the albino's power of transmitting its albino character when paired with a second albino.

Bateson (:03[b]) calls attention to the statement of Dr. C. Carter Blake, printed in the fourth edition of a booklet entitled "Fancy Mice" (Anonymous), to the effect that in two litters obtained from two pairs of albinos, a large percentage of the young was variously pigmented. This result, if true, is unique, and quite at variance with all other known cases. While under certain conditions a reversal of dominance may conceivably take place, it seems more than likely that either an error was made in regard to the true father of the litters in question, or the animals used were not true albinos. The period of gestation for house mice has been shown by Sobotta ('95) to be about 21 days, and the same is also true in the case of the common brown rat (Mailles, '87). If proper precautions were not taken, it might well have been that in the instances cited by Dr. Blake, the albino female had been covered by a pigmented male just before being put with the albino male. Hence a litter containing pigmented young might be born at any time within three weeks after the two had been placed together, and though really fathered by a colored animal, would have been attributed to the albino male. Certainly such a case as Dr. Blake describes should be most carefully established before receiving credence in the light of our present knowledge. Another possible explanation, however, may be suggested, viz., the albinos may not have been *complete* albinos. The occurrence of mice having pigment in the eyes only has been established, and these, though they might pass as albinos, are really of a very different nature. This is discussed further under the head of partial albinism.

Although pure albino mice "breed true" with respect to albinism, this does not imply that all albinos have the same influence in heredity when bred to pigmented animals. That this supposition is clearly erroneous seems to have been first pointed out by Darbishire (:03), and Cuénot has made observations leading to the same conclusion. These results are more fully treated in the discussion of the behavior of colors (*vide infra*).

5. *Summary on heredity of complete albinism.* To sum up the results of experiment and observation on the manner of inheritance of complete albinism, it is clear that this character is recessive in the Mendelian sense to either total or partial pigmentation, so that a union of an albino and a pigmented parent (the latter being understood in this case to be

homozyogous) results in the production of individuals showing the pigment character only, whether that be total or partial. This is true not only for mice and rats but for other mammals also.

When two mice or rats, each having the character complete albinism recessive, are mated, there result 25 per cent of albino individuals. This relation sometimes occurs in single litters of young, but obviously can do so only in lots of 4 or of some multiple of 4. In the long run, however, the totals for a large number of such litters show a very close approximation to the Mendelian ratio of 3 pigmented mice to 1 albino.

That, further, Mendel's law of segregation holds in the inheritance of albinism, may be seen in cases where albinos are crossed with pigmented heterozygotes having albinism recessive. In such crosses the expectation is that pigmented and albino young will be produced in the ratio of 1 : 1. This is found true experimentally, as an average result. In the writer's experiments, it is found that of 13 litters of mice produced by heterozygotes mated *inter se*, in which the number of young was either 4 or 8, 7 litters, or practically one half, show the precise Mendelian ratio of 3 pigmented mice to 1 albino; and of 25 cases taken also at random, in which, from back-crossing of a heterozygote with an albino, an equality of these two classes is expected (the selected litters containing an even number of young), this ratio appears in 12 cases, or a trifle less than one-half.

This result is, on mathematical grounds, about what we should expect. For, in cases where equality of white and of pigmented offspring is expected in the long run, the chances for their distribution in individual litters of four young each are as follows:

All white:	1 chance in 70
3 white: 1 pigmented . . .	16 chances in 70
2 white: 2 pigmented . . .	36 chances in 70
1 white: 3 pigmented . . .	16 chances in 70
All pigmented	1 chance in 70

Consequently in litters of 4 we expect equality of albino and pigmented young in scarcely more than half the individual cases.

Similarly, when the litters consist of eight young each, the chances for the distribution of white and pigmented animals in individual litters are as follows:

All white:	1 chance in 12,870
7 white: 1 pigmented . .	64 chances in 12,870
6 white: 2 pigmented . .	784 chances in 12,870
5 white: 3 pigmented . .	3136 chances in 12,870
4 white: 4 pigmented . .	4900 chances in 12,870
3 white: 5 pigmented . .	3136 chances in 12,870
2 white: 6 pigmented . .	784 chances in 12,870
1 white: 7 pigmented . .	64 chances in 12,870
All pigmented	1 chance in 12,870

The experimental results obtained indicate, therefore, that the production *on the average* of an equal number of gametes of both sorts actually takes place, although separate litters are quite as apt to exhibit a discordant ratio as the theoretical one.

A ratio of 1 albino to 15 pigmented animals is to be expected in cases where the F_1 individuals are interbred at random, the one parent being heterozygous with respect to albinism and either total or partial pigmentation, the other parent having that one only of the last two coat-characters which is not possessed by the heterozygote; where, in other words, three different allelomorphic characters are brought to the union, and the F_1 generation consists of two classes of young, one of which still contains albinism as a recessive character, while the other contains only the two pigment allelomorphs. Generation F_2, obtained by interbreeding at random the young of F_1, should contain six classes of individuals. The actual occurrence of some of these classes has been experimentally demonstrated.

A third possible combination, in which one parent is heterozygous with respect to one pigment character and albinism, and the other is heterozygous with respect to two pigment characters, is theoretically capable of producing four sorts of individuals in F_1, none of which is unpigmented. The actual occurrence of such a result is indicated by the present series of experiments.

Complete albinism, so far as certainly known, is a recessive character in the Mendelian sense, when brought into competition with a pigment character. Two pure albinos when mated, produce albinos only, so far as at present tested, but it must not from that be assumed that any two albinos are physiologically equivalent as regards their influence on the heredity of pigment characters, in crosses with pigmented animals.

B. Partial Albinism.

1. *Manner of occurrence.* Partial albinism is a phenomenon of not infrequent occurrence among mammals and birds, and other organisms as well. In many species the unpigmented areas form part of a definite color pattern and may be in the form of stripes or spots variously disposed. Such markings, however, appear to come under a category different from that of the white areas occurring abnormally in animals that naturally are pigmented over all parts of the body. In the case of such animals, spots or unpigmented areas, when they occur, tend to appear at certain definite places, and the increase of the white areas takes place in such a way as to give the impression that the pigment is shrinking away toward

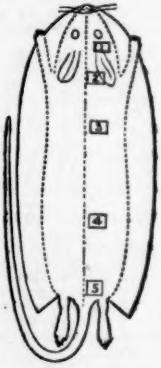


Figure 3.

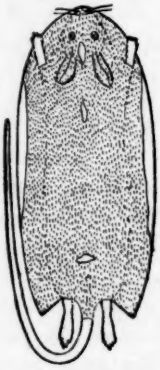


Figure 4.

certain centres more or less definitely situated. The writer's attention was first called to this matter by Professor Castle in the case of guinea pigs, where these centres are especially conspicuous. From a study of a number of spotted mammals the writer has made out in several of them the presence of ten such centres (see Figures 3–6). These are bilaterally arranged five on either side, as follows: (1) A genal centre for the pigment patch which embraces the eye, ear, and side of the face; (2) a nuchal centre for the neck patch; (3) a scapular centre for the patch which covers the shoulder and fore leg; (4) a pleural centre for the side patch; (5) a sacral centre for the large patch which includes the tail, hind limbs, and sacral region. Figure 3 shows in a diagrammatic way the location of these centres in the house mouse. On account of the shortness of the neck in the

mouse, the genal and nuchal centres are close together, and the two patches are generally not distinctly marked off from each other. From a comparative study of other mammals, however, it is found that the genal patch is rather definitely limited in its backward extension to the posterior part of the head proper, so that it is not difficult to assign it limits in cases where the two are fused. On the subject of the arrangement and variation of these patches in piebald mammals, Professor Castle and the writer have in preparation an extended paper based on the examination of a large number of animals.

In a mammal such as the mouse, which normally has total pigmentation, partial albinism seems to occur but seldom in the wild state, and

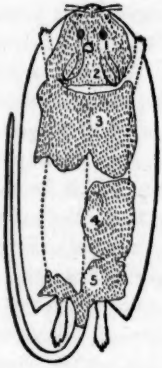


FIGURE 5.

FIGURE 6.

when depigmentation does take place, it is most apt to occur in a small spot on the forehead, at the tip of the tail, or on the mid-ventral line. It is as if the pigment patches emanating from the two nuchal centres, or the two pleural centres, had not quite met, leaving a spot unpigmented on forehead or belly respectively, or as if the sacral patches had not spread to the end of the tail. There is great variation in the degree of isolation of the various pigment patches delimited by the white areas. Figure 4 shows the pattern of a mouse reared by the writer in which appear the beginnings of separation (1) of the genal patches (giving rise to the white streak in the forehead), and (2) of the nuchal and scapular patches (the small white spot in the median line at the nape indicating the boundary of the two). The fore feet are white, showing that the scapular patch has not reached its greatest possible extension.

(3) The pleural patches are separated ventrally, leaving a narrow white belly streak. (4) The pleural and the sacral patches have not fully coalesced on the dorsal part of the rump, leaving thus a median white spot, and the restriction of the sacral patches has given a white tail and white hind feet. Various degrees of increased restriction of pigment toward the different centres are possible, and the ultimate extreme condition is the complete absence of pigment about a centre. Thus, Figure 5 shows the condition obtaining in the writer's black-white male 303. The genal and nuchal pigment patches are practically intact, though a break in the middle of the forehead and a white streak along the throat show that the two former are suffering restriction. A white collar nearly separates the nuchal from the scapular patches, and the latter have shrunk away, as it were, from the belly and fore limbs, while posteriorly a notch in the median dorsal line indicates that a further restriction would divide the color area into right and left patches. One of the pleural patches, that on the left side, has disappeared altogether; the other is entirely free from the scapular patch, and nearly so with respect to the sacral patch of its own side. It will be observed that the single pleural patch tends to encroach very slightly on the area which its fellow normally would cover. The two sacral patches are fairly distinct, the one on the right being more extensive. The two fuse posteriorly and include the root only of the tail. Figure 6 represents a still more extreme case of restricted pigmentation; it is the color pattern of a black-white Japanese dancing mouse obtained from a dealer. The genal patches are reduced so as to leave a wide white blaze on the forehead, and the shoulder patches, too, are very much reduced, though they have not broken from the neck patches. The sacral patches are represented by two very small centres, one on either side of the base of the tail. The pleural patches have disappeared entirely. The writer has seen similar mice in which the shoulder patches also were gone. Hence it is not difficult mentally to picture a mouse in which all the patches have become eliminated, by selection or otherwise, giving a pure white individual with black eyes as the condition of partial albinism whose opposite extreme is an animal totally pigmented except at the tip of the tail. The actual occurrence of a white mouse with black eyes has been established by Bateson (:03', p. 74), who states that to his knowledge "strains of this type have been independently produced twice." Among other animals also individuals of this sort are known. Thus among horses, cattle, dogs, cats, guinea pigs, hens, and even doves, white individuals with pigmented eyes are not uncommon. It seems difficult to obtain such a race

in the case of mice, as the patches about the head are not easy of elimination.

To carry the reduction of pigmentation still farther would be to bring about a reduction of the pigment in the eyes of a black-eyed white animal. Bateson (:03[a]) mentions a strain of black-eyed white mice whose eyes were a "blackish red," so that apparently it is possible to reduce the eye pigment in a black-eyed white animal. Darbishire's pink-eyed, fawn-white mice show that depigmentation of the eye may take place independently of elimination of the coat patches. If the reduction of the patches by proper selection is possible, we may conceive of a total albino mouse derived from a pigmented stock, and so potentially a mosaic, which, nevertheless, if bred to an albino might give totally pigmented young. Evidence of this is found in Bateson's (:03[a]) statement that the black-eyed white mice do not breed true to that condition even *inter se*, and a cross with an albino of dissimilar ancestry would probably have the effect of upsetting the condition of restricted pigment still further. This indeed is the result which, as I am authorized by Professor Castle to state, has usually been obtained by him with guinea pigs. For on breeding together an albino and a black-eyed white animal, the young are more or less extensively pigmented, depending somewhat on the parentage of the albinos used. Other evidence showing the comparative instability of this condition of extreme pigment reduction is afforded by the white cattle of Scotland, the so-called "White Forest breed." According to E. L. Sturtevant ('74) this breed is characterized by the absence of pigment from the entire surface of the body, save the hoofs, horns, and nose-skin, which are black, and the ears, which are usually red. The eyes also are pigmented. The herds of this animal formerly kept in certain private parks of the British Isles show evidence of long inbreeding, and it is known that a severe process of selection has been practised to keep the breed up to the desired standard. Frequently pigment patches occur on the neck or sides of the offspring of two typically marked animals, and such blemishes in the herd are customarily removed at once.

Evidently a case of this sort among plants is that cited by Naudin ('65), in which two varieties of Datura were crossed. The one was an albino race with white flowers (*D. laevis*), while the other was also white flowered, but showed a slight pigmentation of the stem in the region of the nodes (*D. ferox*). This union always resulted in a blue flowered plant similar to the usual *D. tatula*. Evidently the form *ferox* was a partial albino in which the pigmentation was extremely reduced in the

soma, though the cross with the albino served to call forth the production of a greater amount of coloring matter. The precise mechanism by which this result is obtained is not clear; it is uncertain whether there is simply an increase of a pigment-producing ferment, as Cuénot's explanation would imply, whether the cross with an albino serves to upset an unstable condition, or whether some other unknown influence brings about the result. At all events, the facts thus far collected seem to indicate that the albinos used in these cases transmit a character which makes for total pigmentation, and this asserts itself in the first hybrid generation as a character dominant over partial pigmentation.

What is probably an analogous result is recorded by Tschermak (:02) in the case of peas (*Pisum*). The usual type of *P. arvense* is characterized by the presence of red pigment spots at the axils of the leaves. A Swedish variety was obtained which lacked this spot and bred true to the peculiarity. But hybrids obtained by crossing this pea with an albino stock were found to exhibit the red axillary spot. This phenomenon may also be looked upon as a case in which a character emerges from latency under the influence of cross breeding, the character missing in one parent having been transmitted through the albino parent to the offspring, in which it becomes active.

It is clear, then, that a white animal with black eyes is not an albino, but simply a *partial* albino, and care must be taken to recognize this fact in studying the heredity of albinism.

In practically all domesticated animals partial albinism occurs to a greater or less extent, and it is quite possible that the conditions incident to domestication favor its appearance, or at least its propagation. Among animals living under natural conditions also partial albinism is not infrequent, often appearing among small mammals in the form of a white tip to the tail. Thus Miller ('93) records having found white-tipped tails repeatedly in the case of the two eastern species of white-footed mouse (*Peromyscus*), and occasionally in *Mus musculus*, likewise in the vole (*Microtus pennsylvanicus*), and in the common Blarina (*Blarina brevicavda*). In the common jumping mouse (*Zapus hudsonius*) Miller has twice found specimens, otherwise perfectly typical, having a white tip to the tail, 8 mm. in extent. He points out that in the nearly related woodland jumping mouse (*Napaeozapus*) this character has become a distinctive mark. It would thus appear that the character is capable of inheritance and fixation. What causes bring about such a restriction of pigment seems as yet past finding out, but if the ideas already advanced are correct concerning the development of the pigment from

certain centres on the body, the appearance of albinism in certain body regions would seem to be due to a weakening of certain of the centres for pigment development. The writer inbred house mice for four generations in the hope of bringing about by this means some trace of albinism, but none was produced.

2. *Heredity of partial albinism.* Among mice and rats, partial albinism tends to be inherited as a distinct character, so that when two pure-bred spotted animals are mated, all the offspring are spotted, though they may differ from the parents in respect to the precise degree of partial pigmentation. In a paper already mentioned, Castle and Allen (: 03) have referred to these spotted mice as mosaics in which the characters, pigmentation and albinism, are *both* visible side by side in distinct areas of the animal's body, though when the two characters are brought together by the mating of a *totally pigmented* and an *albino* animal, albinism is recessive and does not appear in the soma. For this reason, such a spotted animal might be regarded as a mosaic in which the two characters are so united as not to be segregable in the formation of gametes. As Professor Castle has suggested to the writer, it is conceivable that *incomplete* segregation may take place in a heterozygote containing both the pigment and the albino characters. Such partial segregation would give rise to gametes partaking of both these characteristics, and the union of two such gametes would produce a partial albino. That spotted mice have really had such an origin, however, remains to be proved. It is clear from the experiments detailed in the preceding chapter that there is no evidence for the general occurrence of any but the normal Mendelian segregation of the two characters concerned. Moreover, the fact that two pure-bred spotted animals breed true and produce no albinos, shows that the albino character cannot become, as far as present experience goes, again segregated into a separate germ. If this view be tenable, the spotted or mosaic individual contains both the dominant and the recessive elements side by side in its mature germ cells as well as its soma, and may be symbolically expressed by the term DR. It may, however, with equal propriety be regarded as simply a "mutation" (de Vries) in which the production of pigment is for some reason more limited than it is in the normal individual. Among plants, that variety of Datura in which the fruits have prickles grouped in patches, instead of being uniformly disposed, may perhaps be similarly regarded as exhibiting a mosaic condition, since the thorny character is found to be dominant in heredity over the smooth condition of fruit (Bateson, : 02, p. 23). The fact that in mice the spotted condition is one which cannot be pro-

duced experimentally by simply crossing pigmented with albino individuals is well known (Darwin, '76), and although Crampe appears to have been able to do so with his rats, nevertheless his results are capable of another interpretation, in some cases at least. Thus Crampe ('85) states that the wild gray rat or "species" bred to albinos gave animals entirely gray or else animals with white in the forehead, tail, or belly. Rats of the latter sort, if interbred, gave not only unicolored but spotted young as well, and also albinos. In this case, however, the possibility is not excluded that the so-called species was *not* an actual wild gray rat, but simply one which was gray through reversion, and had had one spotted parent.

These facts lead to a consideration of the behavior of the spotted or partial albino condition in crosses. As previously stated, when two pure-bred spotted individuals are mated, the young are all spotted. The spotted character is quite independent of color, however, so that it is possible to mate piebald mice, which differ in the color of their pigmented areas, and yet to obtain offspring all spotted. This shows that the mosaic, if such it be, retains its integrity strongly, or in other words *the localization of the pigment at certain points is a condition which is heritable.* Yet the degree of this localization varies, and in a single litter individuals may occur having pigment patches more or less extensive than those of their parents. The important point is that breaks between the pigmented areas do occur in the young of partially albino mice, be these breaks large or small.

A different result is obtained by breeding partial albinos to certain stocks of complete albinos. In the writer's early experiments a large number of young was obtained by breeding black-whites to albinos of a stock whose ancestry was unknown. In all cases the resulting young were practically totally pigmented. Some showed no trace of albinism in the pelage, though others had white toes, or a white tip to the tail, or even a few scattered white hairs. Only one had a white spot on the belly. This is much the same result as that recorded by Haacke ('95), who, in crosses of a Japanese spotted stock with albinos, obtained mice of a uniform color over the entire body, save that in occasional animals small flecks of white appeared in the usual places (i. e., on the forehead, tail, or belly). Von Guaita ('98) by a similar cross obtained a like result. The influence of the albinos in these cases seems to be to upset the condition of localization of the pigment, so that the pigment patches become more extensive, tending to cover the entire body surface as in totally pigmented animals. In explanation of this observation, it is suggested that

the character total pigmentation may be transmitted by albinos, and when so transmitted dominates over the spotted condition. How this may possibly take place, an ingenious suggestion made by Cuénot (: 03) indicates. This investigator believes that the formation of pigment is due to the action of some ferment upon a chromogenic substance, and that an albino may transmit the former apart from the latter. It might be that the gamete of such an albino brings in a quantity of the ferment sufficient to produce a greater amount of pigment, and so the resulting individual is much less marked with white than the spotted parent. Such considerations are, however, purely theoretical.

If the character total pigmentation be dominant, in the Mendelian sense, over partial pigmentation, it should be possible by interbreeding heterozygous individuals to obtain 25 per cent of offspring having the spotted character. Of the 75 per cent of self, or wholly pigmented animals, one-third are expected to be pure in respect to the character total pigmentation, and the remainder to be heterozygous.

From the writer's self-colored heterozygotes (F_1) obtained by crossing black-white mice with albinos which transmitted the character total pigmentation, a second generation was bred, consisting of 10 spotted, 27 nearly unicolor, and 15 albino young. As the albino young were not tested to discover which of the two pigment characters they transmitted, it is necessary to disregard them. Of the 37 pigmented animals, therefore, one-fourth, or 9, are expected to be spotted, and there were actually 10 of that nature. Von Guaita in his generation F_2, which was obtained in a similar manner, got 10 spotted and 20 self-colored individuals from the heterozygotes, an excess of 2.5 spotted young over the expected number. Darbishire (: 03) records a similar case. He intercrossed spotted Japanese dancing mice with albinos of two stocks, the one pure bred, the other cross-bred. The latter sort had "appeared from time to time in the litters of piebald mice kept in the Oxford Laboratory for embryological purposes"; the former were purchased of a dealer. The cross-bred albinos, since they are presumably of spotted parents, will transmit the spotted character, so that Darbishire's result, 25 spotted and 4 unspotted young, is quite what might be expected. The four unspotted individuals probably came from an albino which was heterozygous with respect to the two characters, total and partial pigmentation. From his pure-bred albinos, Darbishire obtained 36 spotted and 61 unspotted mice, a fact indicating that at least some of these albinos transmitted the character making for total pigmentation. The result is due apparently to the transmission of pigmentation characters through the albinos, not to the

relative degree of in-bredness or pure-bredness of the albino stocks. Moreover, the characters total and partial pigmentation are inherited quite apart from the character complete albinism, so that in the F_2 generation it is possible to obtain both spotted and self-colored animals having the character complete albinism recessive. An albino having the spotted character may be regarded as a spotted mouse in which the spots do not show, perhaps because of the absence of chromogenic substance, if we adopt the theory of Cuénot (:03).

Darbishire's mice offer another point of interest in this connection. The spotted Japanese individuals were of a peculiar strain, having *pink* eyes. All the F_1 heterozygotes had dark eyes, so that we may suppose the pigmented parents of the albinos to have had dark eyes. From his second generation, obtained by interbreeding the dark-eyed heterozygotes, Darbishire had 17 pink-eyed spotted mice, 36 dark-eyed individuals, and 13 albinos. These last doubtless represent both the pink- and the dark-eyed condition potentially, but until tested they may be disregarded. It is expected, therefore, that 25 per cent of the pigmented individuals will show also the pink-eyed character. This, in fact, is practically the outcome, for 17 young are pink-eyed, 13+ being expected. The character of the albinos could be tested by back-crossing them with the pink-eyed pigmented stock, and some would probably give pigmented mice, all of which would have pink eyes, while others would give young some with pink, some with dark eyes.

To test further the character partial pigmentation, the writer has back-crossed with spotted mice both albino and pigmented individuals which might be supposed to be heterozygous with respect to the two characters. The derivation of the animals used is,

spotted × non-spotted or self

self (spotted recessive),

and the expectation is that by the cross with a spotted mouse, self-colored and spotted offspring will result in the ratio, 1 : 1. This was practically the result obtained. Table P contains a list of crosses of this nature.

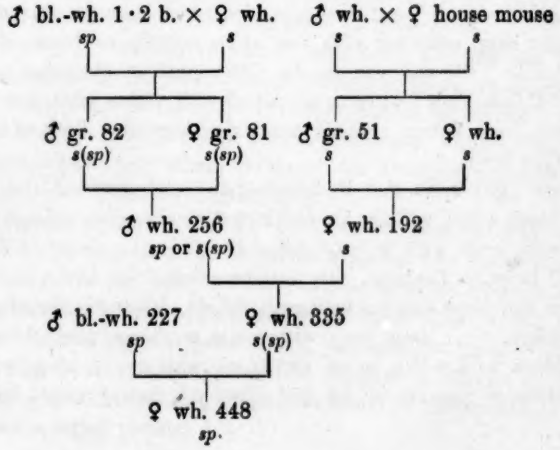
The expectation is that the two classes will each consist of 14.5 individuals, so that the deviation amounts to but 0.5 for each class, — as close an approximation as is possible in an odd number of offspring. The writer purposely selected as the heterozygotes for these tests *albinos* coming of a cross between spotted and self-colored mice, in order to throw light on the suggestion of Bateson (:03[b]) that a segregation of pigment characters

TABLE P.

Parents.	Spotted Young.	Self-colored Young.
♂ gr.-wh. 352 × ♀ wh. 389 . .	2	2
♂ ch.-wh. 392 × ♀ wh. 447 . .	2	3
♂ ch.-wh. 423 × ♀ wh. 433 . .	4	2
♂ bl.-wh. 454 × ♀ wh. 439 . .	3	2
" "	3	1
♂ bl.-wh. 304 × ♀ gr. 422 . .	1	4
	15	14

occurs among the albino animals as well as among those which are pigmented. It is clear that a segregation did take place among the albinos with respect to the two pigmentation characters under discussion.

The writer also has an albino mouse, an extracted recessive, which appears to transmit the spotted character, but not the character giving total pigmentation. The following scheme shows the pedigree of this individual. The letters *s* and *sp* in connection with each animal indicates its character, whether *self* or *spotted*, the combination *s* (*sp*) indicating a self-colored heterozygote.



Two spotted mice, each having albinism recessive, must transmit to their *albino* young, as well as to their pigmented offspring, the character partial pigmentation; hence an albino of spotted parentage should give only spotted young on being bred to a spotted animal. This supposition the writer has tested and found to be correct.

It remains to discuss more in detail the relation of total to partial pigmentation. The experiments thus far performed do not show an absolute dominance of either condition over the other, though the tendency is in favor of the dominance of total pigmentation in the offspring of a spotted mouse and a mouse unmarked with white, as the following experiments indicate. The writer obtained three young by crossing a spotted black-white mouse (No. 303, Figure 5) with a gray, wholly pigmented house mouse. Two of the young were entirely gray, while the third was gray all over except for a white ring near the tip of the tail. In another case a black-white male was bred to a totally black mouse of house-mouse extraction, and of the three pigmented young obtained all were entirely black, save that the toes were rather lighter colored. They differed in no respect, however, from their mother. In another case a totally gray mouse resulted from the union of a D and a DR gamete, and when bred to an albino of spotted extraction, it gave two plainly spotted and two unicolor young. The result is perhaps similar to that obtained in the cross of the spotted with an albino stock not known to come of spotted parents, for the young tend to be wholly pigmented, though frequently they show a white tip or ring on the tail. Moreover, further intercrossing of these heterozygotes often gave "golden-agouti" and chocolate mice, which show no trace of white, but might have offspring with the white tail tip or forehead stripe. Both Haacke ('95) and von Guaita ('98) speak of obtaining only unicolor mice from their first cross of spotted with albino mice, but Haacke adds that these hybrid animals sometimes showed a fleck of white on forehead or belly.

Crampe ('85) states that by breeding the wild gray rat ("species") to the black-white variety, he obtained 4 totally gray animals and 36 which were gray with white "Abzeichen," in the shape of flecks on the tail, belly, or forehead. By interbreeding these latter, he obtained gray rats and black rats exhibiting all the six classes of coloration which he describes, viz.; gray, gray with white markings, gray-white, black-white, black with white flecks, and black with no markings whatever. The unions of gametes in the first described mating would be

$$\begin{array}{rl} D + D & = \text{gray ``species,''} \\ DR + DR & = \text{black-white,} \\ \hline 4\ DR{\cdot}D & = F_1\text{, mostly with white flecks.} \end{array}$$

This generation, F_1, interbred, should give gametic unions as follows:

$$\begin{array}{r} DR + D \\ DR + D \\ \hline DR + 2DR{\cdot}D + D = \text{theoretical classes,} \\ 77 \ : 133 \ : \ 25 = \text{observed numbers,} \\ 58.75 : 117.5 : 58.75 = \text{calculated numbers.} \end{array}$$

Crampe obtained the three theoretical classes: plainly spotted (DR), hardly spotted (DR·D), and unspotted (D). These classes occurred in something like the anticipated proportions, though it is clear that there were more spotted rats than expected. Moreover, as his first cross (F_1) showed, the union of DR and D does not always give spotted animals, and this fact might serve to reduce still further the class D, which is less than 50 per cent of what it was expected to be. These facts may indicate incomplete segregation of the two characters, which, indeed, differ only in degree.

In general, however, it is clear that in mice and rats the cross of a wholly pigmented variety with one having partial pigmentation serves to reduce the extent of the white areas in the offspring, so that the latter may either show very slight traces of albinism at the places where albinism is most apt to occur, or they may show no white at all.

3. *Summary on heredity of partial albinism.* To sum up, partial albinism among mammals which normally are wholly pigmented occurs in certain definite places in the shape of white patches or breaks between pigmented areas. These areas, in suffering reduction, become diminished toward certain centres, of which there are ten arranged symmetrically, five on either side of the longitudinal axis.

According as the pigment patches are little or more reduced, or disappear entirely, various degrees of partial albinism may be recognized. The extreme on the one hand is that condition in which albinism occurs at the extremities of the appendages, or as small flecks at the points where two adjacent pigment patches had just failed to meet. The opposite extreme is that condition wherein pigment production is found only in the eye, and even here a certain amount of reduction may take place in the coloring matter.

A partial albino may be regarded as a mosaic exhibiting, in its soma, two characters which, when segregated, are to each other as dominant (pigment) to recessive (albinism). Two partial albinos breed true to that (partial albino) condition, even though each contains an albino character *recessive* (compare formula 2*a*, p. 73). Necessarily, therefore, two-thirds of the spotted offspring of such *heterozygous* animals (DR·R) come of the union of a gamete containing the character partial albinism (DR) with one bearing the completely albino character (R). Yet the union of a spotted animal with an albino *not of spotted parents* produces young which tend to be totally pigmented. An albino coming of *two spotted* parents, on the other hand, when bred to a *spotted* individual, probably produces only *spotted* offspring, for this union is manifestly similar to that producing spotted young, where both spotted parents have albinism recessive.

Complete pigmentation in mice tends to be dominant over partial pigmentation, although the dominance is not always perfect. In rats, Crampe seems to have found the tendency to be toward an intermediate condition. In general, the result of a union of a pure *spotted* and a pure *unspotted* (pigmented) individual is to greatly reduce the amount of albinism in the young of the F_1 generation or to eliminate albinism altogether, the outcome being, in one case, an intermediate condition, in the other, dominance of the character total pigmentation.

Partial albinism, then, tends to be inherited as a distinct character and in accordance with the Mendelian principles; in mice it behaves as a recessive in relation to total pigmentation.

VI. Heredity of Pigment Characters.

1. *The gray coat.* The "wild gray" or typical house-mouse coat has been shown by Miss F. M. Durham (Bateson, : 03[b]) to owe its color to the presence in the hairs of three pigments, black, chocolate, and yellow; these may be present in slightly different proportions, thus producing a lighter or a darker gray, or one with more than the usual amount of yellow (sable). For the purposes of this paper, however, "gray" is understood to mean that sort of coat in which all three pigments are present, no particular regard being paid to the slight variations of lighter or darker tint. This gray coat under cross-breeding may undergo resolution, giving several distinct color types characterized by an absence of one or two of the three pigments. In the writer's experiments the types thus obtained were: (1) black mice, whose pigments were black and chocolate, (2) golden agoutis, containing only the chocolate and the yellow

pigments, and (3) chocolate mice, containing the chocolate alone. Yellow mice in whose pelage is only the yellow pigment are a well-known type, but the writer was unable to obtain any thorough segregation from his other stocks. To avoid confusion, these types are here referred to by the terms used in Bateson's paper (:03[b]) on the types of fancy mice and rats. The hairs of the mice bred by the present writer have been examined with the microscope and the pigment elements found to be as stated by Miss Durham.

Wild gray house mice breed true to that color, so far as observed. The writer bred a considerable number from a pair captured in Cambridge, and four generations of inbreeding failed to produce any but gray animals.

Four house mice were bred to albinos obtained of a Boston dealer, and by reciprocal crosses 67 young were produced, all of which were gray. Among these was a litter of three of a very light gray, but they unfortunately died while only a fortnight or so old. Subsequently the same parents produced normal gray young only.

The gray heterozygotes obtained from this cross were interbred, and produced, in addition to the expected albinos (extracted recessives), a number of pigmented animals, 40 in all, which with a single exception were gray like their parents. The exception was a mouse entirely black. Here evidently was a case of segregation, the yellow pigment being entirely lacking. Although this individual appeared coal black, the presence of the chocolate pigment was manifest at times when the pelage was moulted, the new hair appearing brownish. Bateson states that he has not seen any black mouse whose hair did not contain also the chocolate pigment. To account for the presence of this black mouse it may be assumed that among the gametes of both its hybrid gray parents there were present some which lacked the yellow pigment character. Two such gametes must have united to produce the black individual. The black character was probably transmitted through the *albinos* used, for, as will be shown farther on, this stock seemed regularly to produce about 25 per cent of gametes bearing the black pigment character, the remainder having the gray character. In the formation of gametes, therefore, the gray heterozygotes must have produced some sex cells which lacked the yellow pigment character. It is conceivable that this result may have been brought about by a resolution of the gray character in such a way that yellow and chocolate passed into one gamete, black and chocolate into another. A part of the gray heterozygotes of generation F_1 were back-crossed with the albino parent, and of the 31 pigmented animals so

obtained, 3 were black. This fact points to a segregation of the color characters both in the gametes having the albino character and in those having the pigment character. In crosses with heterozygotes from this house-mouse-albino stock no colors other than gray and black were obtained.

Of the black mice obtained from this stock by the process of back-crossing already described, some proved to have albinism recessive, while others were pure in respect to albinism, showing that the black condition was not one depending for its production on the union of a recessive with a dominant gamete, though the former (recessive gamete) was probably effective in transmitting pigment. The black mice were found to produce only black pigmented mice and albinos; their case is more fully discussed under the next heading.

Gray heterozygotes obtained by crossing house mice with albinos were bred to animals similarly colored but descended from black-whites and albinos. All of their pigmented young, 19 in number, were likewise gray.

The reversionary gray coat of mice derived from a cross between black-white and albino mice is not always transmitted intact, but commonly undergoes more or less resolution of its pigment characters.

Thus, three pairs of gray-white mice, whose grandparents on the side of each parent were respectively a black-white and an albino, and whose parents were gray heterozygotes, produced gray young in large proportion, but also a few golden-agouti and a few black individuals. The total offspring from three such pairs was 14 gray-white, 1 black-white, 4 golden-agouti-white, and 1 albino. This seems plainly to be a case of resolution of the gray pigment character, as there was no golden-agouti ancestor, so far as known.

Gray house mice, when bred to fancy stocks of other colors, usually give gray young only. Thus, only gray mice were obtained by the writer from a cross of a female house mouse with a black-white male. These gray young were then bred to gray heterozygotes derived from a cross of a house mouse with an albino, and only gray offspring resulted. Dehne ('55) records crossing a yellow mouse with a house mouse, hoping thereby to propagate the yellow variety, but all the young were gray, and the experiment was given up. Cuénot (:03) finds that the cross of wild gray mice with black mice always results in gray offspring in the first generation, but in the second generation the black character reappears under close breeding, in the proportions demanded by the Mendelian laws for recessive characters, i. e., 3 gray to 1 black.

For rats, Crampe ('77) found that the wild gray type was dominant over both the albino and the black-white variety in the first generation, so that only gray rats were produced. A "Mestiz" (apparently a gray heterozygote), one of whose parents was a wild gray rat, when bred to a black-white rat, gave 4 gray and 5 black offspring, a result comparable to that of Cuénot, in which black acted as a recessive character.

It is therefore clear that the wild gray coat of the species type is strongly dominant over those types obtained from it through resolution of the three pigment characters. The wild gray coat also shows less tendency to break up into black, chocolate, and golden-agouti than does the reversionary gray coat seen in cross-breds from fancy black-white and albino stock. This will be shown in detail farther on.

2. *The black type.* According to the researches of Miss Durham (Bateson, : 03[b]), the black coat contains two sorts of pigments, — a black and a brown, or chocolate. No case was found in which black occurred alone. This result I am able to confirm. The brown pigment is visible in the new hairs when the black animals are moulting, but it is much less conspicuous in the fully grown hairs. Since only these two pigments are found in the black coat, it is natural to inquire what has become of the third or yellow pigment. Two explanations are possible: either yellow is absent because of its having become latent, or else through segregation it has been lost entirely. The latter alternative seems the more probable; the evidence for and against it will be discussed later.

In general, two black mice breed true to that color, though under some circumstances it is possible to obtain chocolate animals also. The writer has reared a considerable number of black-white mice and they have never produced any but black-white young (except, of course, where albinos appeared in consequence of the recessive occurrence of albinism in both parents). Mice wholly black, which came of a house-mouse stock, also behaved in a similar way, giving blacks only, among the pigmented individuals. A black-white mouse bred to a black mouse of house-mouse extraction produces only black young, some of which may at times show a trace of white at the tip of the tail or on the toes. Bateson (: 03[b]) notes a similar result in the case of self-colored blacks bred to black-whites, and asks therefore if black-white may not be recessive to black. As the writer has shown in the chapter on albinism, it is more properly a case of dominance of complete pigmentation over partial pigmentation.

In looking over the records given by von Guaita ('98, : 00) it is found that in all cases where black mice were paired, the pigmented young were black (or black-white), and a similar result was recorded by Haacke

('95) for the black-white Japanese waltzing mice which he bred. In general, therefore, the black type seems to be a definite one which breeds true to that pigment character, and does not show the presence of the yellow pigment.

The cross of the black with the albino type is one of considerable interest. Haacke ('95) bred black-white mice of a stock imported from Japan to some albinos whose ancestry is unrecorded, and obtained usually gray mice indistinguishable from the wild gray ones. More rarely, a wholly black mouse came of this same union. Von Guaita ('98, :00) repeated the experiment, crossing black-white Japanese dancing mice with an inbred stock of albinos. He obtained twenty-eight young, all uniformly gray like the house mouse. A like result is recorded by Davenport (:04), only gray young having resulted in two litters from black mice bred to albinos.

In the writer's experiments, as previously recorded (Castle and Allen, :03), two black-white mice were crossed with albinos, the result being that some of the offspring were gray, others black. The spotted animals were both males and were known to give only black-white young when bred to mice of that color character. Their gametes, then, did not transmit the yellow pigment character, and the above result shows the same to have been true also of some at least of the gametes of the albinos, for there were in all 15 black young in addition to 28 gray ones. An explanation of this result is suggested as follows: Since the black mice produced gametes having only the black character (or rather, black-chocolate), it is clear, on the present hypothesis, that some of the albinos were producing gametes with only the black character, while a large number were producing gametes whose union with those of the black mice brought together all three pigment characters, resulting in the production of gray young. If we suppose that the albinos used came of a mixed ancestry, as seems probable, and that one-half the gametes formed by them contained latent the complex gray character, while in the other half the latent gray element underwent resolution, the following combinations of pigment characters would result from the mating described:

a.

bl.-ch. + bl.-ch. = gametes of ♂,
wh. (gr. latent) + wh. (gr. latent) = gametes of ♀,
4 gr. = F_1.

b.

bl.-ch + bl.-ch. = gametes of ♂,
wh. (yell.-ch. latent) + wh. (bl.-ch. latent) = gametes of ♀,
2 gr. + 2 bl. = F_1.

In the one case (*a*), the gray character transmitted by the albino is sufficient to produce only gray offspring. In the other case (*b*), the gray character, latent in the albino, is supposed to undergo resolution so that gametes are formed one-half of which contain the yellow-chocolate character and one-half the black-chocolate character. In the two cases wherein the yellow character unites with the black of the black-white parent, gray offspring result, since all three of the pigment elements are thus brought together. In the other two cases, however, both unions are of gametes having only the black-chocolate elements, and so only black young result. If this hypothesis be correct, there should be on the average 3 gray to 1 black young produced by the cross described. There were actually obtained 43 young, so that the expected result is ($32\frac{1}{4}$ or) 32 gray to ($10\frac{3}{4}$ or) 11 black mice. The observed result was 28 gray to 15 black, a fairly close approximation.

In a second case a black-white male having albinism recessive was bred to these same albino females. Assuming, as before, that in one-half the cases the gametes of the albinos contained the gray character, and that in the remaining cases the gray had been resolved, the combinations of gametes to be expected are:

a.

bl.-ch + bl.-ch. = gametes of ♂,
wh. (gr. latent) + wh. (gr. latent) = gametes of ♀,
2 gr. + 2 wh. (gr. latent) = F_1.

b.

bl.-ch. + bl.-ch. = gametes of ♂,
wh. (yell.-ch. latent) + wh. (bl.-ch. latent) = gametes of ♀,
1 gr. + 1 wh. (gr.) + 1 bl. + 1 wh. (bl.) = F_1.

The expected result is therefore: $\left\{\begin{matrix}1 \text{ white (black latent)} \\ 3 \text{ white (gray latent)}\end{matrix}\right.$ + 3 gray + 1 black. The actual result was 21 albinos + 10 gray + 2 black. The albinos are here in considerable excess, but if the 12 pigmented individuals are alone considered the expected result would be 9 gray to 3 black

mice, so that the agreement between theoretical and observed is reasonably close. The albino offspring were not all tested, hence it is not possible to say whether there were any among them which contained the black character only, as this hypothesis would demand. On the whole, it seems reasonable to believe that segregation did take place among the albinos used, in the manner indicated.

That albinos differ in their ability to transmit pigment characters has been shown by Darbishire (:02) and Cuénot (:03). The latter had three sorts of albinos: (1) from gray ancestors, (2) from black parents, (3) from two "yellow" mice of a complex ancestry. The same black male bred to the first sort, produced always gray mice; bred to the second sort, always black mice; bred to the third sort, gray, black, or yellow mice. To explain this result Cuénot has formulated the ingenious and attractive theory that pigments are produced by the action of specific ferments on a chromogenic substance, and that an albino may transmit the former but not the latter. He supposes that the albino of gray parentage transmits the ferments corresponding to the different sorts of pigments which constitute the gray coat, and so the union of such an albino with a pigmented animal produces gray offspring. In like manner the albino of black parentage transmits only the ferments which make for black. Assuming that there is some such process as Cuénot has indicated, it is easy to conceive of segregration taking place in such a way that certain of the gametes of an albino provide one sort of ferment and other gametes another sort. Thus, if the albinos used by the writer should in half of the cases produce gametes with the ferments that give the gray coat, while the other half had the ferments either for black-and-chocolate or for yellow and chocolate, such a result as was obtained is readily explainable. At present, however, such an hypothesis does not admit of positive proof, although it seems clear that the albino of mixed ancestry does in some way contribute the third pigment element to produce gray offspring.

The gray heterozygotes resulting from this cross of black-whites and albinos of mixed ancestry, when interbred, show a further resolution of the pigment characters. Those used by the writer were practically of a uniform gray all over, with only an occasional trace of albinism, so that it is evident that the albino parents transmitted the character total pigmentation. Therefore, in generation F_2 about $\frac{1}{4}$ of the animals are spotted. The colors obtained from the gray heterozygotes are: gray (32), gray-white (11), black (8), black-white (1), chocolate (1), and golden-agouti (2), as well as albinos (21).

The *black* heterozygotes of this same (F_2) generation, when interbred, produced only black-whites (4), blacks (7), and albinos (6). Thus the black failed to undergo further resolution, and it contained no other pigment in a recessive condition. This result is like that recorded by von Guaita, whose black mice, when interbred, produced no other color type than black.

When, however, gray heterozygotes were bred to black heterozygotes, both of the F_1 generation, the result was similar to that given by the gray animals bred *inter se*. For from this mating there resulted: gray (14), gray-white (5), black (5), black-white (2), chocolate (4), golden-agouti (4), pied golden-agouti (1), albinos (5).

These results show that gray with its *three* pigment elements is more readily resolvable than is the black, which consists of but *two* pigments. As will be shown presently, it is sometimes possible to obtain chocolate mice from black parents, hence it might have been expected that individuals of this color should occur among the offspring of the gray and black heterozygotes. But the presence of golden-agouti among these offspring seems plainly due to the introduction of the third or yellow pigment character through the *gray* parent. Moreover, when resolution does take place, the yellow element is the first to disappear, so that black individuals are next in point of numbers to the gray ones, and are nearly twice as numerous as either the golden-agouti or the chocolate mice. Leaving the albino young out of consideration, it is seen that in the cross of gray heterozygotes, resolution of the pigments took place with such frequency as to produce 12 individuals lacking one or two of the three pigments, as against 43 which possessed all the pigments and so were gray. In the cross of gray with black mice of the same (F_1) generation, 15 showed resolution of color, as against 19 which were gray. It is difficult to draw any definite conclusions as to the proportions of germ cells in which the pigment characters undergo resolution. For it is hardly probable that all the gray individuals result from the union of gametes each of which has the gray character, since this color might be produced by the union of any two gametes which *together* contained the three elements; thus gray × black, gray × chocolate, gray × yellow, as well as black-chocolate × yellow, or yellow-chocolate × black might result in the production of gray individuals. The writer has been unable to obtain mice with the yellow pigment alone by this process of segregation, but this negative result is not surprising when we recall that in the experiments of von Guaita (:00) neither chocolate nor golden-agouti types were produced, though these have appeared repeatedly in the writer's experiments.

Possibly this difference in results is due to a difference in the nature of the albinos used, and in the readiness with which the pigment elements undergo resolution. If, as is apparently the case, all the black animals in the writer's experiments contained both black and chocolate pigments, it follows that when the black or the yellow pigment elements became segregated from the other two in gamete formation, they must regularly have been eliminated, so that the individual resulting from two gametes of a similar pigment nature was either golden-agouti or black (i. e., black-chocolate). Similarly if the black and the yellow elements remain coupled, they are regularly eliminated, leaving only the chocolate element in the gamete, for no black-yellow type of mouse is certainly known. The chocolate element on the other hand may occur either alone or in combination with black or with yellow, giving in the one case, on union with a similar gamete, a chocolate individual, and in the other, either a black (i. e., black-chocolate) or a golden-agouti.

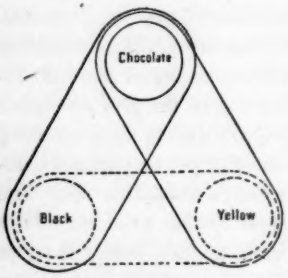


FIGURE 7.

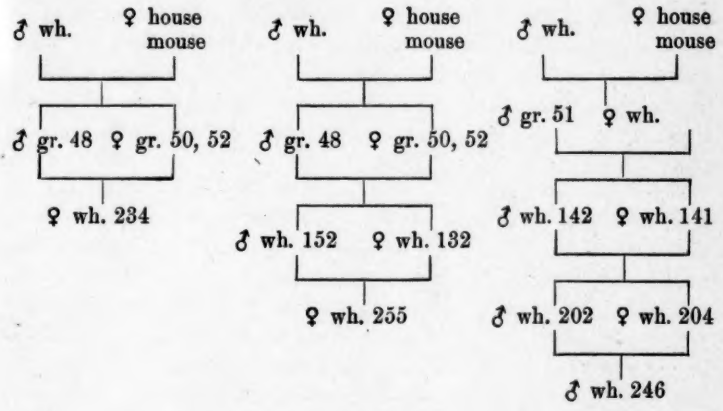
Solid line indicates colors or combinations of colors which may result by segregation.

Dotted line indicates colors or combinations of colors which did not result by segregation in the writer's experiments, though theoretically possible.

The researches of Cuénot (: 03), as well as those of other experimenters along similar lines, show clearly that in crosses between albino and pigmented individuals, the former, although showing no pigment colors, have nevertheless an equal share in the transmission of pigment characters. Whatever may be the nature of the pigment-producing elements, it is plain that the albino possesses these, and that they undergo segregation as in pigmented animals. The occurrence of the black heterozygotes, in the cross of black-white with albino mice, was certainly due to the union of gametes each containing the black-chocolate characters alone. For black mice regularly produce gametes with these pigment characters only, and it is therefore evident that the albino parent produced a certain number of gametes bearing the black-chocolate pigment character (or none). These uniting with those produced by the black-white mouse, resulted therefore in black animals having albinism recessive. Yet with the albino character went also the ability to transmit black-chocolate, *but no other colors.*

In a few cases albinos were crossed with black mice derived from the

heterozygotes of house-mouse and albino parentage. Two of the black mice had albinism recessive, the third, though born in the same litter, produced no albinos. The ancestry of the albinos used in this cross is shown in the following diagram:



From each of these three pairs of black and albino mice, both gray and black young were obtained, the total being 10 gray, 4 black. There were also 16 albinos, as well as two which were dark-eyed but died before attaining the coat pigments. Here, again, if it be assumed that one-half the gametes of the albino contain the gray character and that in the other half segregation of this character takes place, so that at least one-quarter of all the gametes produced have the black character, then one in four of the pigmented offspring should be black, the others gray. In the experiment, 4 out of 14 mice *were* black, the number demanded by the hypothesis being 3.5.

In a similar case, where black animals from spotted stock were bred to the writer's original lot of albinos, there were produced 4 gray mice and 1 black one in addition to 3 albinos. The evidence therefore favors the idea that the albino may transmit the gray character entire in a certain proportion of its gametes, while the rest transmit regularly only certain components of that character.

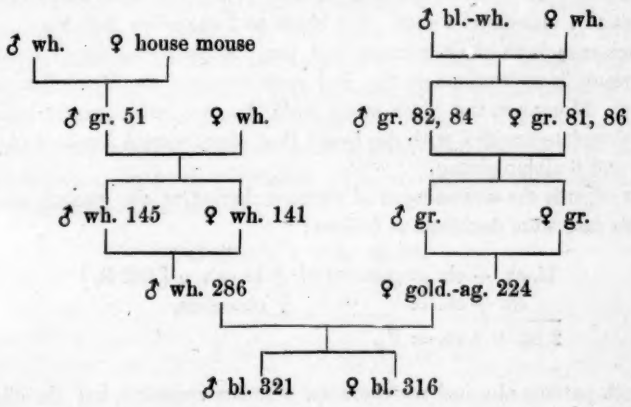
In the course of these experiments, it was found that two black mice, if paired, produced only black young, even though one parent had the character albinism recessive. Since one-half the unions in this case take place between gametes containing respectively the albino and the black-

pigment character, it follows that the albino gametes of a black animal contain only that pigment character which gives black. Consequently if two black animals, each having albinism recessive, are crossed, the albinos that result contain only that pigment character that makes for black. The truth of this hypothesis may be readily tested by breeding these albinos to pure black animals, the expected results being that only black offspring will be produced. This expectation has been fully realized in the experiments of the writer. Albino mice both of whose parents were black, have, in numerous crosses, produced no other color type than the black, when bred to black mice. This held true irrespective of the origin or degree of relationship of the black animals used. Whether black-white mice were used, or those wholly black derived from the house-mouse cross, or even a black stock purchased of a dealer, the result was the same, so far as the production of black pigment was concerned. This result is the same as that obtained by Cuénot (:03), who had albinos from a cross of two black mice, and found that they gave only blacks when bred to black animals. A similar case is recorded in "Taf. 2," of von Guaita's (:00) later contribution. His pair 3, consisting of an albino and a black animal, produced, in 11 litters, 16 black-white mice, 7 black, and 20 albinos. The parents of the albino used in this cross were a black and a black-white mouse, so that their albino young would possess the black pigment character only.

Additional evidence that the writer's black mice and the albinos obtained from them possessed only the two pigment characters that give black (i. e., black and chocolate) is afforded by the cross of black with chocolate animals. This cross, even supposing the pigment character of the black animal in some cases to become resolved into black and chocolate, would then afford but two combinations of pigments, namely, black with chocolate giving black, or chocolate with chocolate giving chocolate. If, however, the yellow character is present in a latent state in either parent, the cross should bring it into activity and a proportion of gray young should result. Thus far the writer has known of no case where gray young did occur in a mating of this sort. Two crosses were made in which a black-white female (403) was bred to two chocolate-white males, and each of the two litters thus obtained consisted of an albino and four black-white mice. That is, black was dominant over the chocolate. Again, an albino, both of whose parents were black, and which therefore should possess the black character, was bred to a chocolate female, and of the four young produced, two were albinos and two were black. Another albino mouse, also of black parentage, was bred

to a chocolate male, and all the seven young were black. A like result was obtained in other crosses of black with chocolate mice. These experiments further indicate that the *albino actually transmits pigment characters* and is not, as might perhaps be thought, simply purified of pigment characters. For if the white parent transmitted no pigment, the pigmented young in this last case would have been chocolate.

If, then, black be dominant over chocolate, it should be possible to obtain both black and chocolate offspring by interbreeding the heterozygous black animals. This result was actually obtained by the writer in case of two black animals which came of a cross between an albino and a golden-agouti. As will be shown farther on, the black character doubtless came through the albino, which was of a stock known to transmit this character. The golden-agouti parent probably supplied the chocolate character. The following diagram shows the ancestry of the two black mice:



In three litters from this pair of black mice, there were obtained 6 black, 5 chocolate, and 1 white young. If each black parent produced, by segregation, gametes half of which were of the black, and half of the chocolate character, one-fourth of the young would be chocolate and the rest black as regards their pigment qualities. Of the 12 young actually obtained 5 were chocolate (3 being expected). The single albino which occurred was not tested to determine in which pigment category it should be placed. Additional evidence that chocolate is recessive toward black is afforded by the following cross. A black mouse, itself a cross between a black and a chocolate, and hence assumed

to be heterozygous with respect to these two characters, was back-crossed with a chocolate individual. The expected result, on Mendelian principles, is an equality of black and of chocolate young. The single litter of three young obtained from this pair were two of them chocolate and one black, hence fulfilling the expectation as closely as is possible with an odd number of offspring. The following additional cases also point to the same relation of black to chocolate. Bateson (:03[b], p. 83) includes, among a series of matings supplied by a Mr. F. G. Parsons, two cases in which black mice produce chocolate young. These additional cases are:

"(8) bl.-w. ♀ C (? DD) . . . × bl.-w. ♂ *a* (DR) = 3 bl.-w., 1 br.-w.
(37) bl. ♀ $D^2(D \times a)$ (DR) × bl.-w. ♂ *a* (DR) = 2 bl.-w., 2 bl., 1 br."

Thus the same male gave, by two black females, in the one case 3 black-whites to 1 chocolate, and in the other, 2 blacks and 2 black-whites to 1 chocolate, a total of 7 black to 2 chocolate individuals. If in each case both black parents had the chocolate character recessive, this result is approximately the 3 : 1 ratio expected on Mendelian principles. Moreover, the black-white male ♂ *a* was subsequently bred to two chocolate females, with the result that there were 4 black, 4 chocolate, and 6 albino young.

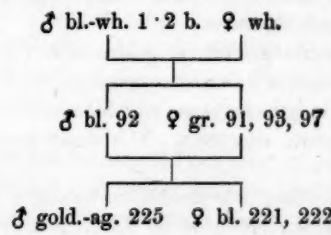
As regards the transmission of pigment characters, the gametic unions in this case were doubtless as follows:

bl.-ch. + ch. = gametes of ♂ bl.-wh. *a* [DR·R,]
ch. + ch. = " ♀ chocolate,
2 bl. + 2 ch. = F_1.

Both parents also had the character albinism recessive, but the albino young resulting from the cross would contain one or both of the two pigment characters latent, as could be shown by back-crossing them with the chocolate parent. If the chocolate character be recessive, it is expected that one-half the young will have the black, and one-half the chocolate character. If the albinos possess the same equal distribution of the pigment characters as do the pigmented animals, the Mendelian expectation is fully realized here. In the crosses given by Bateson, black and chocolate are the only pigments produced, although albinos, chocolates, and blacks are freely interbred. The albinos are doubtless from two chocolate or two black parents, or from a chocolate and a black, and thus do not contain the yellow element necessary to produce the gray

coat. In the cases cited by Bateson, therefore, chocolate seems to be present as a character recessive toward black; for, except in the cases noted, black breeds true and is dominant over chocolate. Bateson's white females, A and B, were probably from chocolate parents, and so transmitted that pigment character only, for when bred to the heterozygous male, A, they both gave black as well as chocolate offspring, but when bred to chocolate males, chocolate pigment alone was produced. A third albino female, D, was probably heterozygous with respect to the black and the chocolate characters, for she gave young of both these colors by a chocolate male. In all cases where chocolate mice were interbred, chocolate was the only pigment obtained. The possibility of an alternative dominance of the one color over the other should not be lost sight of, but the writer's experiments do not clearly indicate such a relation.

The relation of the black to the yellow character was tested by breeding black mice to golden-agoutis. Each animal in this mating had the chocolate pigment present in the hairs, and the union of the two brought together all three of the pigment elements. Hence the cross might be expected to produce gray animals, and perhaps those of other colors as well, if the pigment characters undergo resolution. In the course of the writer's experiments three black mice, sisters, were bred to a golden-agouti male, their brother. The ancestry of these animals, so far as known, was as follows:



Three litters were obtained by this mating, giving a total of 7 gray and 2 black mice.

In a second case a golden-agouti male (485) was bred to an albino of black parentage, so that the union of the pigment characters was similar to that in the previous case. The three young obtained from this pair were all gray. Davenport (: **04**) records a somewhat similar case, in which a cross of a black with a yellow mouse resulted in a single gray young. Bateson (: **03**^{b}) states, further, that Miss Durham by crossing

yellow with black mice obtained sables (i. e. gray with brighter flanks), dingy fawns (i. e. predominately yellow associated with dark pigment), and also some fully black individuals, but the yellow mice used by Miss Durham were presumably not golden-agoutis.

In the case of the gray and the black young obtained by the writer, it may have been that the former represented those animals in which a combination of all three pigment characters had taken place. The case of the few black animals, however, requires a different explanation. If they represent a combination of black-chocolate and of yellow-chocolate characters, then the yellow must have become latent. If, however, in the case of the yellow-chocolate character chocolate has been segregated in certain instances, then in those instances equal numbers of black and of gray mice should result. This is expressed by the following scheme:

bl.-ch. + bl.-ch. = gametes of black parent,
yell.-ch. + ch. = " " golden-agouti,
2 gr. + 2 bl. = F_1.

If this segregation takes place in half of the gametes produced by the golden-agouti, the total result is 3 gray to 1 black mouse, which is a relation not greatly different from that obtained, viz.: 7 gray, 2 black. But if we assume this segregation on the part of the golden-agouti, it seems reasonable that it should take place among the gametes of the black mice too, giving thus a certain number of chocolate individuals. Yet none occurred. Miss Durham's result also failed to show such a resolution on the part of the black character.

It is much more probable that the golden-agouti here employed may have contained the chocolate character recessive, or, at any rate, that the segregation resulted in gametes some of which had the yellow-chocolate, and others the chocolate character. The result would be the same in either case.

Unfortunately the writer was unable to obtain a second generation from the black offspring produced by the cross between a black and a golden-agouti. A few of the gray young were tested, however, with the following results. In one case, two of the gray young were bred together. If the gametes formed were of two sorts, corresponding to those produced by the black and the golden-agouti parents respectively, the following combinations would be possible:

bl. + gold.-ag. = gametes of gray ♂,
bl. + gold.-ag. = " ♀,
1 bl. + 2 gray + 1 gold.-ag. = offspring.

The expected result, provided that the gametes retain their purity with respect to pigment characters, is that one-fourth the offspring will be black, and one-fourth golden-agouti, while the remaining one-half will be gray, since they represent unions involving the three different sorts of pigment characters. The actual result was of this nature, for the three classes were present in the two litters obtained in the following numbers of individuals: 2 black, 2 gray, 8 golden-agouti. This, then, has the appearance of a simple case of Mendelian inheritance, wherein two pigment characters (black and golden-agouti) are produced in separate gametes equally numerous.

A further test of this hypothesis was made by back-crossing one of the gray (black × golden-agouti) mice with a golden-agouti female. If the gray mouse produces gametes whose pigment characters have kept their integrity, the two sorts of unions possible would give equal numbers of gray and of golden-agouti young, thus:

bl. + gold-ag. = gametes of gray male,
gold.-ag. + gold.-ag. = " gold.-ag. female,
2 gray + 2 gold.-ag. = offspring.

If, however, as in certain cases previously described, it be assumed that one-half the unions only are of this sort, while in the other half the gametes of the golden-agouti parent undergo resolution, the result in this latter case would be:

bl. + yell.-ch. = gametes of gray male,
ch. + yell.-ch. = " gold.-ag. female,
1 bl.-ch. + 2 gold.-ag. + 1 gr. = offspring.

The total result would be four (50 per cent) of golden-agouti young, three (or 37½ per cent) of gray young, and one (or 12½ per cent) black, if the union of black with yellow results in black. These three classes of colors were all present in the single litter obtained, but the proportions were: one golden-agouti, three gray, one black. This experiment is not conclusive, therefore, but indicates that in some cases the gametes may retain their pigment characters intact, whereas in other cases these characters may undergo resolution. On the other hand, it is conceivable that the gray animal represents merely the coexistence of the three characters in the germ-cells as well as in the soma, and that it is a matter of chance whether at gamete formation the three pigment elements become variously segregated or remain together in one gamete. Such

a state of affairs, however, seems improbable, since, if it existed, it would be possible to obtain from two pure gray animals offspring some of which would show merely the black, the yellow, or the chocolate pigment characters. No case of this sort is known to the writer. Further and more extensive tests will be necessary to a full understanding of the processes here taking place, but it seems for the present that pigment segregations occur chiefly, if not exclusively, under the influence of cross-breeding with other color varieties or with albinos.

Among rats, the black pigment character appears to behave much as in the house mouse. Black rats breed true, as observed by Crampe ('85) and others. Crampe also found that black or black-white rats, if they contained albinism recessive, produced only black pigmented young, in addition to the Mendelian proportion of albinos.

In the case of rabbits, however, black seems to be of a somewhat different nature. Woods (: 03) finds that on interbreeding black rabbits a small proportion come gray or yellow. His figures are: 105 black, 9 gray, 8 yellow. This may indicate simply an impure black, or the yellow element may be latent or recessive in certain individuals. In the case of the albino 112, *both of whose parents were black*, it was found that, with three exceptions, only black and albino young were produced when it was mated with a black heterozygote. The three exceptions were all gray young, and came of a black animal whose parents and four grandparents were black. However, since black animals bred *inter se* may produce a small proportion of gray young, the result from breeding black to black is practically the same as that obtained by breeding black to albino of black parentage, as has been found true of mice.

3. *The chocolate type.* The chocolate mice used in these experiments were derived from the gray heterozygotes of the cross between a black-white and an albino stock. According to Bateson (: 03[b]), his pupil, Miss Durham, finds the hairs of chocolate mice to contain only the chocolate pigment, and this observation the writer has been able to confirm by a microscopical examination of hairs from his chocolate mice.

Of the mice of this type obtained from the gray heterozygotes above mentioned, some were found to have the albino character recessive, while others were pure with respect to albinism. Mice of the latter sort, when interbred, produced only chocolate offspring. A similar result was obtained by mating a pure chocolate animal to one having albinism recessive. In this case the gametic unions (formula 5, p. 72) are of two sorts:

ch. + ch. = gametes of pure chocolate,
ch. + wh. = " heterozygous chocolate,

2 ch. + 2 ch. (wh.) = offspring.

Consequently, one-half the chocolate young from this sort of a cross result from the union of a gamete of the chocolate pigment character with one of the albino character. The latter, however, carries potentially the chocolate character, so that the result of the union is to produce a chocolate animal, since no other color element is introduced. It follows that if two chocolate mice of this sort are interbred, the 25 per cent of albinos resulting will in like manner possess the chocolate character.

The unions of gametes are (formula 2):

ch. + wh.
ch. + wh.

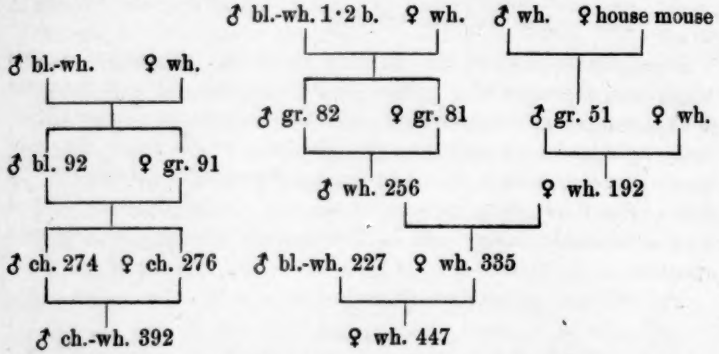
ch. + 2 ch. (wh.) + wh.

This the writer has been able to demonstrate by actual experiment. Such albinos from two heterozygous chocolate parents, when bred to chocolate mice, gave chocolate young only. The obvious inference from results of this sort is that *the albino gametes formed by a pigmented animal which has the albino character recessive, possess the same pigment potentiality as the pigment bearing gametes formed by the same animal.* An albino, therefore, both of whose parents had the chocolate character only, will produce young of that character, when mated with a chocolate animal. This fact is doubtless the explanation of Bateson's (:03[b]) statement that "Miss Durham has found chocolate a simple dominant over albino," for her albino was presumably of chocolate parentage.

A different result is obtained by mating chocolate mice with albinos of mixed ancestry. The writer made several matings between chocolate mice and albinos, the latter being extracted recessives from crosses between gray house mice and the original stock of albinos previously mentioned. Four different albinos were paired with as many chocolate mice, and of the 22 resulting young, 20 were gray and 2 black. The black was presumably transmitted through the albino stock, which, as has been shown, seemed to produce a certain number of gametes having the black character. The predominance of the gray character is strong. Bateson (:03[b]) records a cross of similar result, wherein a chocolate and an albino gave gray young.

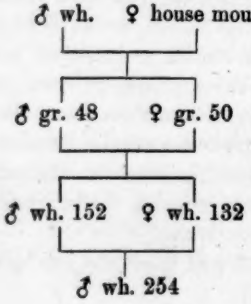
An interesting and different result was had by breeding to a chocolate-

white mouse an albino of a yet different extraction. The following scheme shows the ancestry of the pair so far as known:



The single litter from this pair consisted of 5 young, of which 1 was chocolate, 2 were gray, and 2 black. Assuming that the chocolate parent produced gametes having the chocolate character only, it is necessary to suppose that the albino transmitted through some of its gametes the black character only (producing the black offspring), and through others the gray character (from the gray grandparents three generations back). If some of the germ cells having the gray character should produce by resolution gametes having the chocolate character only, the chocolate class would be produced also. At all events, it seems clear that the third or yellow element was contributed by the albino parent, which in turn had inherited it from the gray mice on the maternal side.

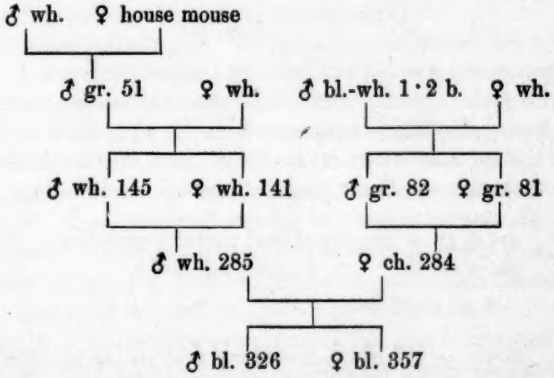
In order to test further the heredity of the chocolate character, the writer mated together two of the gray heterozygotes coming from a cross between chocolate mice and albinos, which in turn were the descendants of a house mouse and the writer's original albino stock. The ancestry of the albino parent of the two gray animals is as follows:



The albino male, 254, gave gray animals on being bred to the chocolate female, 264. These gray offspring, bred *inter se*, produced in three litters, 1 chocolate, 2 golden-agouti, 2 black, 12 gray, and 5 albino young.

It is difficult, in view of the small number of young obtained, to formulate a wholly satisfactory hypothesis to account for the combinations of color characters which here took place. The chocolate offspring are to the other pigmented young as 1 : 16 instead of being as 1 : 3, the expected ratio. Apparently, a certain number of gametes bearing the black character were produced by the gray heterozygotes, and some of these gametes may have united with those bearing the chocolate character, thus producing black offspring, while at the same time reducing the number of pure chocolate individuals. The large proportion of gray young may indicate either the presence of unresolved gray in some of the gametes, or the recombination of the three elements of a gray which underwent resolution at gamete formation. The white male, 254, must have contributed the characters other than chocolate which appear in his grandchildren.

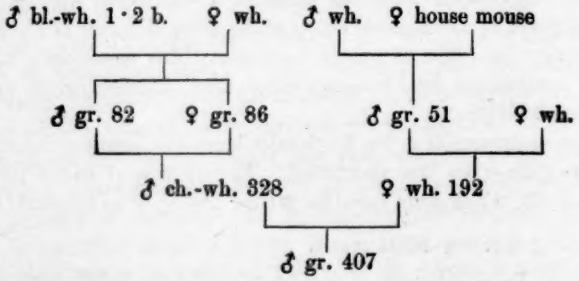
The occurrence of a few black mice in crosses between chocolates and certain albinos has been mentioned. The ancestry of two of these black individuals, which were saved for further testing, is as follows:



If the chocolate parent produced only gametes having the chocolate pigment character, these black individuals must have resulted from the union of such a chocolate gamete with one from the albino containing the black character, and hence must be heterozygous with respect to the two characters. The albino was descended from a stock of albinos

known to transmit the black character in a certain proportion of cases, hence this supposition seems plausible. Moreover, from the writer's crosses of black and chocolate mice, as well as from the data given by Bateson for similar crosses, it seems fairly clear that the chocolate under these circumstances may behave as a simple recessive towards black. In this case, the black heterozygotes, on being back-crossed with chocolate mice, should give both black and chocolate individuals in the ratio, 1 : 1. This, in fact, was approximately the result obtained. In six litters a total of 10 black and 13 chocolate mice was obtained, each class being thus within two of the expected relation, 11.5 : 11.5.

A different result came from back-crossing with a chocolate mouse a *gray* heterozygote whose parents were respectively a chocolate and a white mouse. The ancestry of the gray animal follows:



This gray mouse gave, in two litters by a chocolate mouse, 3 black, 3 gray, and 3 golden-agouti young. If the chocolate mouse produced only gametes having the chocolate pigment-character, while those of the gray mouse in half the cases underwent resolution and in the other half retained the gray character unresolved, the gametic unions would be:

gr. + gr. = gametes of gray parent (unresolved),
ch. + ch. = " chocolate parent,
4 gr. = offspring.

bl.-ch. + yell.-ch. = gametes of gray parent (resolved),
ch. + ch. = " chocolate parent,
2 bl. + 2 golden-agouti = offspring.

The result is that three classes of young, gray, black, and golden-agouti, are produced, in the proportions 2 : 1 : 1. In the experiment these three classes were present, but in the proportions 1 : 1 : 1.

One of the three gray young from the cross of the gray heterozygote and the chocolate female was back-crossed with the same chocolate mouse, its mother. The single litter obtained consisted of 2 gray, 1 black, and 1 chocolate offspring, a fact which probably indicates that the gray animal produced a certain number of gametes with the black character, and others with the chocolate character. The number of young obtained is, however, too small to allow of generalization.

This same gray male was also mated with an albino female which transmitted the black pigment character. If chocolate always goes with black, the combinations of pigment characters represented by this mating are probably as follows:

bl.-ch. + yell.-ch. = gametes of gray parent,
bl.-ch. + bl.-ch. = gametes of albino parent,
2 black + 2 gray = offspring.

The observed result was 3 black, and 4 gray mice, so that, although the totals obtained are small, it seems probable that the gray character did undergo resolution in the manner suggested.

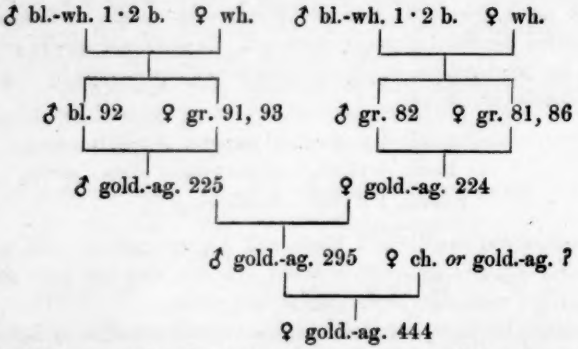
Evidence has been adduced from the experiments cited by Bateson and from those performed by the writer to show that the black coat character may be a simple dominant over chocolate. The relation of the chocolate character to golden-agouti may next be considered.

4. *The golden-agouti type.* This is the type of mouse which Bateson describes as possessing the chocolate and the yellow pigments, but not the black. It therefore has a dingy or tawny appearance. Microscopical examination of the hairs of certain mice bred by the writer confirms this description.

These mice occurred in small proportion among the young of gray heterozygotes, themselves the offspring of black-white and albino mice, and hence are evidence that a resolution of color characters took place in the gametes of their gray parents. Since the golden-agouti contains but the two pigments, yellow and chocolate, the utmost number of varieties obtainable by interbreeding two animals of this sort is manifestly three, assuming that both pigment characters undergo resolution in the same manner. These would be, a pure yellow, a pure chocolate, and the combination of the two, or golden-agouti. In the writer's experiments, only the last two types have appeared. No pure yellow mouse has been obtained among all the various crosses, which have produced hundreds of offspring. This fact may point to some physiological peculiarity in case of the writer's stock, by reason of which the yellow pigment character

was unable to assert itself to the same degree as did the black and the chocolate, or perhaps the complete resolution never took place.*

A number of matings were made between golden-agouti mice, and the usual result was offspring all golden-agouti in color. In case of two pairs of golden-agouti mice, however, chocolate young resulted, as well as those of the parents' color. The ancestry of the first of these two pairs is as follows:

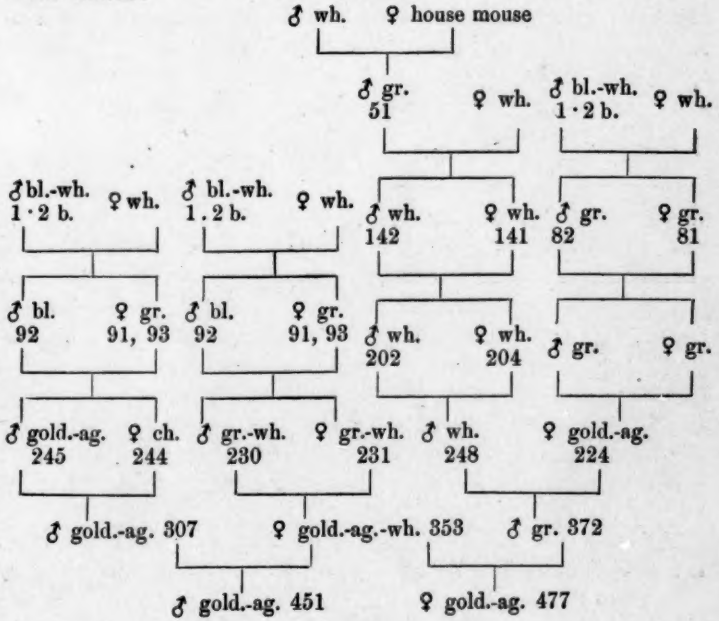


The golden-agouti female, 444, was bred back to her father of the same color, 295. The writer is not absolutely certain which of two animals was the mother of the female 444, a chocolate or a golden-agouti, both of which happened to be with the ♂ 295 at the time. More probably, however, a chocolate mouse was the mother. At all events, on back-crossing the golden-agouti daughter with her father, 3 golden-agouti and 2 chocolate young resulted. If both animals in this cross had the chocolate character recessive, this result is readily explicable. It is not entirely clear, however, that this was the case. If chocolate be recessive to pure golden-agouti, it is plain that ♀ 444 is heterozygous with respect to the two characters. It therefore remains to show that her father, 295, was of a similar nature. The parents of ♂ 295 were both golden-agoutis, the one from two gray parents, the other from a gray and a black parent. The black parent could produce, by resolution of its pigment characters, only the black or the chocolate. Assuming that the latter character only was present in some of the gametes of the black animal, and that one of these united with a gamete from the gray animal that contained both the chocolate and the yellow

* Bateson, in a letter to Professor Castle, received some time since, suggests that the yellow color of certain fancy mice may be due, not to resolution of the wild gray coat, but to crossing with *Mus sylvaticus*, "which has almost certainly taken place."

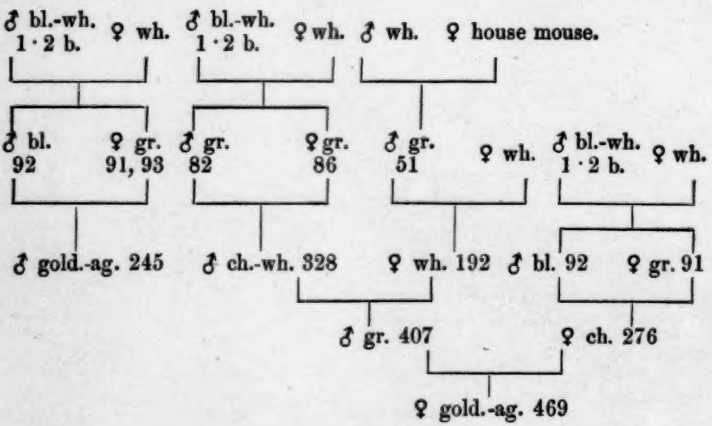
characters, but not the black, then the golden-agouti, 225, may well have retained the chocolate character recessive. Golden-agouti ♀ 224, from two *gray* parents, may be assumed to contain no chocolate *recessive*. The mating of 224 and 225 will then result in golden-agoutis of two sorts, the one pure, the other with chocolate recessive, and 295, of course, must be taken as of the latter class. This explanation is put forward tentatively, pending test by further experiment, but another possibility is also not to be overlooked, namely, that the color characters of a golden-agouti may undergo resolution. If the yellow and the chocolate pigment characters become segregated into separate gametes, then it is clear that golden-agouti as well as chocolate young would result, but in addition there should be some pure yellow offspring as well. The fact that none have yet occurred, speaks against a complete resolution of the yellow-chocolate combination. Possibly, however, the resolution of the yellow-chocolate takes place, only in such a way that gametes are formed which are respectively yellow-chocolate and chocolate, as regards their pigment characters.

The second pair of golden-agoutis that produced chocolate offspring as well as those of their own color, were of the following rather complicated descent:



Both animals of this pair, numbers 451 and 477, had albinism recessive, that character having been handed on in this condition through four generations in case of the ♂ 451. For in the first litter obtained from them there were 3 albino, 2 chocolate, and 1 golden-agouti young. It is difficult to see how the female of this pair could have inherited a recessive chocolate character, though the male might conceivably have done so, through the chocolate grandparent.

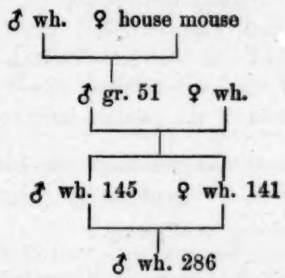
If chocolate be recessive toward golden-agouti, a cross between "pure" animals of these two colors should result in offspring of the latter pigment type only. Only two crosses have thus far been made by the writer between these two varieties. In the one, a golden-agouti male, 245, was bred to a chocolate female, 244, and in three litters there resulted 10 chocolate to 7 golden-agouti offspring. In the second case, a golden-agouti female, 409, was paired with an albino of chocolate parentage, known by tests to have the chocolate pigment-character only. Two young, a chocolate and a golden-agouti, resulted, so that these two pairs of mice are comparable with respect to the pigment characters they transmit. If, then, the golden-agouti parent of each pair can have possessed chocolate in a recessive condition, the approximate equality of the two sorts of young among the offspring is readily explicable on Mendelian principles. The ancestry of the two golden-agoutis is as follows:



If the golden-agouti ♂ 245 contains the chocolate character recessive, it must have come from the black parent through resolution. The gray

parent probably supplied a gamete with the chocolate-yellow character, so that a golden-agouti offspring with chocolate recessive was produced. A somewhat similar process may have taken place in the case of golden-agouti ♀ 469. One parent was chocolate, the other gray. A resolution of the gray character into black and yellow-chocolate may have taken place, and a gamete of the latter pigment-character, uniting with one from the chocolate female 276, would produce a golden-agouti with the chocolate character in double strength, perhaps segregable. In any event, it seems clear either that the two golden-agoutis here considered produced gametes, some with the pigment character which they themselves showed and others with the chocolate character, or else that there is no necessary dominance of either pigment character over the other, but that sometimes one and sometimes the other dominates.

A number of crosses were made between golden-agoutis and albinos, the results of which varied according to the nature of the albinos used. Four golden-agouti mice were bred to albinos descended from gray house mice and the writer's original stock of albinos. In a total of thirty-five pigmented offspring, two were black and the others gray. The albino parent of the two black young produced also four gray mice in the same litter. Her ancestry is as follows:



The black character probably came through the albino stock, which, as was pointed out in discussing the cross of black mice with that stock, seemed to produce about 25 per cent of gametes with the black character. Moreover, a segregation of pigment characters must also have taken place in case of the golden-agouti female, probably into chocolate and either yellow or yellow-chocolate, else the black young could hardly have resulted. For any other combination of the pigments indicated would have given gray, not black. The latter color, then, probably resulted from the combination of a gamete having the black character

with one having the chocolate character, the former produced by the albino, the latter by the golden-agouti. The black offspring, on this hypothesis, may contain the chocolate in a recessive, or at least in a segregable condition. Fortunately the two black young were a male and a female, and they were therefore mated. In three litters, they produced 6 black, 5 chocolate, and 1 albino offspring. On Mendelian principles, 25 per cent or 3 of these young are expected to be chocolate, as regards pigment characters. There are actually 2 more chocolates than expected, disregarding the albino, whose character was not determined. It therefore seems possible that these two black mice did arise in the manner suggested, and produced gametes, some of which were black and some chocolate, as regards pigment characters. This same pair has been previously mentioned in discussing the relation of chocolate to black.

The gray heterozygotes resulting from the cross of golden-agoutis with albinos may have originated either (1) by the dominance of the gray character which came from the house mouse through the albinos, or (2) by the union of the yellow-chocolate character furnished by the golden-agouti parent with the black character, which, as well as gray, the albinos transmitted, though to a lesser degree. If, now, at the formation of gametes the color characters undergo segregation to the extent only of undoing the original (heterozygous) combination of gray and chocolate-yellow, or black and chocolate-yellow, it is plain that generation F_2 will consist of offspring exhibiting three types of color, as seen in the following diagram of the possible unions:

gr. + yell.-ch. = gametes of gray hybrid of first sort,
gr. + yell.-ch. = gametes of gray hybrid of first sort,
3 gr. + 1 gold-ag. = offspring.

bl.-ch. + yell.-ch. = gametes of gray hybrid of second sort,
bl.-ch. + yell.-ch. = gametes of gray hybrid of second sort,
1 bl. + 2 gr. + 1 gold.-ag. = offspring.

gr. + yell.-ch. = gametes of gray hybrid of first sort,
bl.-ch + yell.-ch. = gametes of gray hybrid of second sort,
3 gr. + 1 gold.-ag. = offspring.

The chances in favor of the third combination are twice as many as for either of the other two, hence generation F_2 should consist of young

of three color types in the proportions: 1 black, 11 gray, 4 golden-agouti. The writer actually obtained, in five litters, 1 black, 14 gray, 4 golden-agouti young, as well as 5 albinos, which were not tested. The close agreement of the observed with the calculated total seems to corroborate the conclusion previously stated, that the writer's original albino stock produced gametes some with the gray, some with the black pigment character. It also is good evidence of the segregation of the several pigment characters of the heterozygote in such a manner as simply to unloose them from their combination practically unchanged. Five males and four females contributed to the result just given, but only one of the females was proven to have the black character among her gametes, while the male by which she had the black mouse subsequently died before further tests could be made. The same female by three other of her brothers gave only albino, gray, and golden-agouti young.

To test the matter still further, however, three of the same lot of gray males were back-crossed with golden-agouti females. Assuming as before that some of the gray animals produce gametes with the *black* and the golden-agouti characters respectively, and others those with the *gray* and the golden-agouti characters respectively, the possible combinations are as follows:

gr. + yell.-ch. = gametes of gray parent,
yell.-ch. + yell.-ch. = gametes of golden-agouti parent,
2 gr. + 2 gold.-ag. = offspring.

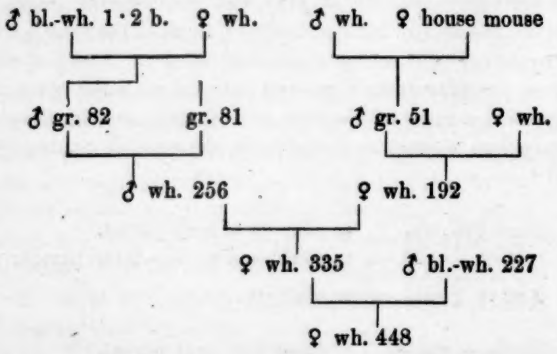
bl.-ch. + yell.-ch. = gametes of gray parent,
yell.-ch. + yell.-ch. = gametes of golden-agouti parent,
2 gr. + 2 gold.-ag. = offspring.

The expected result is that only gray and golden-agouti young will be produced, and that these two classes will be equally numerous. This result was realized qualitatively, but not quantitatively, for there were actually produced 19 gray and 7 golden-agouti young. In other words, there are nearly one-quarter fewer golden-agoutis than expected. If this discrepancy be simply the result of chance, the explanation suggested may still be considered valid, yet the excess of gray animals is so great that it seems hardly proper to ignore it entirely.

Having thus followed through the results of crossing golden-agoutis with albinos of mixed extraction, it remains to mention two other crosses in which the albinos used were of a yet different nature as regards pig-

ment characters. A cross was made between a golden-agouti male and an albino female of black parentage, which therefore had only the black pigment character. This union brings together in the heterozygote all three pigments, and consequently only gray offspring are expected. All the eight young from this pair were, in fact, gray. The result is, therefore, quite similar to that obtained by mating black with golden-agouti mice, for, as previously stated, gray young usually are produced. Black individuals may result, however, from such a cross as this. Their occurrence is due probably to the union of a gamete having the black character (from the black parent) with one having the chocolate character (from the golden-agouti parent).

Finally, a golden-agouti was mated with an albino female of the extraction indicated by the following diagram:



This albino, 448, when mated with a golden-agouti male, 484, produced 2 gray and 2 golden-agouti young. The ancestry of the black-white grandparent, 227, is unknown, beyond the fact that it was of a stock which had been crossed with chocolate as well as with black individuals. In this mating, it is necessary to assume a segregation of characters in such a way that one-half the gametes of the albino female, 448, contain no black element. Union of such gametes with the chocolate-yellow gametes of the golden-agouti male would produce golden-agouti young. The gray character may have come wholly through the white female, 335, certainly its black constituent did, so that it seems necessary to assume also that the black-white ♂, 227, had chocolate recessive.

After many crosses, it was at last possible to obtain albinos both of whose parents were golden-agoutis. The same mating produced also

golden-agouti and chocolate young. It is therefore expected that these albinos, on being back-crossed with mice of their parents' type, will give either chocolate or golden-agouti young, but not gray or black offspring. This experiment is still in progress.

5. *Comparison with Mirabilis.* The behavior of pigments in the case of mice seems to be somewhat similar to that recorded by Correns (:02) in certain varieties of Mirabilis. Several types of blossoms are recognized which, as regards pigment characters, may probably be reduced to three, viz.: (1) red, with which is to be included the rose-type, a "dilute" form of red; (2) yellow, which occurs also in a dilute or *yellowish* form; and (3) the albino. These several types breed true as a rule. Red corresponds to gray in mice, and is probably a combination of red with yellow chloroplasts. Pied varieties occur, as with mice. Correns found that red × albino gave all red blossoms, which shows either that red is a simple dominant over whatever pigment-character the albino may have contributed, or that the latter also contained the red character. The ancestry of the albinos is not given. A cross of albino with rose resulted, however, in rose flowers, so that the former may have transmitted red in the dilute form. At all events, no yellow flowers were produced. A third cross was made between the yellowish stock and the albino. The latter doubtless had the red pigment-character present in dilute form, and was dominant over yellow, for rose flowers were produced. This result is like that obtained by pairing albino mice of gray ancestry with other types lacking one or two of the three color elements, so that the gray results either through dominance or through combination of all the color characters. When the albino type of Mirabilis was crossed with the bright (i. e., undiluted) yellow type, *full red* flowers resulted. The albino used in each of these crosses with the yellow sort must have transmitted the red character in dilute form, for with the *dilute* yellow type dilute red or rose flowers resulted, while with the *full* red type full red flowers were produced. The former cross is therefore quite the same as that in which dilute red and dilute yellow are crossed, giving blossoms of the former or rose type. It is therefore fairly clear that the albino forms of these plants may transmit pigment-characters just as do the albino mice. The data given by Correns as to the behavior of the spotted character do not show very conclusively whether or not it is recessive toward the character total pigmentation. One cross of the albino with mottled white-and-red gave some of the spotted type and a less number that were all red.

VII. Conclusions.

From the experiments here recounted, the following conclusions as to the heredity of color characters in mice are drawn:

(1) *Albinism.* Complete albinism is a character recessive toward either partial or complete pigmentation. Heterozygotes, from a cross of pigmented with albino individuals, produce gametes having the albino character and those having the pigment-forming character in approximately equal numbers. The chance combinations of gametes from two such heterozygotes give rise, in the long run, to pure dominants, heterozygotes, and recessives, in the proportions, 1 : 2 : 1. The pure dominants and the pure recessives breed true *inter se* to the pigment-forming and the albino characters respectively. A heterozygote bred to an individual of either pure class produces, as an average result, equal numbers of heterozygotes and pure animals.

Partial albinism is a condition in which the pigment is reduced around definite body centres, so that unpigmented areas occur between the pigment patches or at their borders. Ten such centres may be distinguished in the mouse, arranged symmetrically five on either side of the median plane. These centres represent a cheek patch, a neck patch, a shoulder patch, a side, and a rump patch. Various degrees in the reduction of the pigment patches occur, or the patch may be eliminated altogether. Partial albino, or pied individuals, breed true to that condition, but partial albinism behaves toward complete albinism as a recessive character, although the heterozygote may sometimes show an intermediate condition. Moreover it is possible for albino mice to transmit either the character total pigmentation or partial pigmentation, or an albino may be heterozygous with respect to these two characters so that, when bred to a pied mouse, equal numbers of pied and of self-colored offspring result.

When pure self-colored mice or rats are bred to pied animals having albinism recessive, generation F_1 consists of two sorts of pigmented individuals both of which are heterozygous, one with respect to the characters total and partial pigmentation, the other with respect to total pigmentation and albinism. A random mating of the F_1 individuals results in the production of pigmented and albino offspring in the ratio, 15 : 1. A like result is obtained if the parental generation consists of a pure pied animal and a totally pigmented one having albinism recessive. Generation F_2, obtained by interbreeding the offspring of such parents, consists theoretically of six classes of individuals, viz.: D, DR, D·DR,

D·R, DR·R, and R. Most of these classes have been demonstrated to be actually present.

If the hypothesis advocated by Cuénot be correct, that pigment is produced by the action of specific ferments on a chromogenic substance, and that albinos carry the former but not the latter, then it must be assumed that the two characters opposed in a cross of a pigmented with an albino form are: (1) presence of chromogenic substance, and (2) absence of chromogenic substance. At all events albinos may transmit pigment-characters, even though they themselves show no trace of pigment.

An albino that transmits the character partial pigmentation may be looked upon as potentially a spotted mouse in whose soma the pigmented areas do not show, perhaps because the necessary chromogenic substance is lacking. The spotted condition may be due to a decrease in the amount of both the chromogenic substance and the specific ferments as compared with the amounts of these substances in a totally pigmented animal.

2. *Pigments.* (1) The gray coat of the house mouse contains the three pigments, black, chocolate, and yellow, as has been stated by Bateson (: 03[b]), and this combination as found in the wild animal is strongly dominant over any of the colors shown by fancy varieties (with the possible exception of yellow, which the writer has as yet had no opportunity to test). Therefore when wild gray animals are bred to varieties of other colors, gray offspring result.

By interbreeding gray heterozygotes, themselves from a cross between gray house mice and albinos, a few black offspring were obtained, indicating that a resolution of the gray color may have taken place in a few cases. No further resolution of the gray from house mouse crosses was obtained.

In the case of gray heterozygotes resulting from a cross of fancy black-white with albino mice, resolution took place to the extent of producing the golden-agouti and the chocolate, as well as the black type.

(2) Animals of the black type breed true to that color. This statement holds good even if one or both of the parents contain albinism recessive. For in this case the gametes having the albino character carry also the specific "ferment" or whatever it may be, that stands for black.

It follows that an albino, both of whose parents are black, transmits the black character. Such an albino, bred to black animals, is found to give young having the black-chocolate pigment-characters only.

Black mice bred to albinos of gray or of mixed ancestry produce

gray and sometimes also black offspring, according as the gray character present in the albinos remains unresolved or undergoes resolution.

The black-pigment character appears to be dominant over the chocolate character, so that a black mouse, or an albino bearing the black character latent, gives only black young when bred to a chocolate individual. These black heterozygotes bred *inter se* may produce both black and chocolate offspring, in approximately the ratio, 3 : 1, or if back-crossed with chocolate mice, the two classes may appear in nearly equal proportions among the young.

When black mice, or albinos bearing the black character, are bred to golden-agoutis, the three pigments constituting the gray coat are brought together by the union, and gray offspring result. Black young may also occur, in small numbers, indicating either a *resolution* of the yellow-chocolate character of the golden-agouti, or the *segregation* of the chocolate character present in either a recessive or a latent condition in the golden-agouti parent. It should, therefore, be possible to obtain chocolate young also from the cross of such a golden-agouti with a black animal having the chocolate character recessive.

No evidence has been obtained to show that black may be a simple dominant over golden-agouti, for gray offspring regularly result from mating pure black with pure golden-agouti mice. From such gray heterozygotes, a second generation was obtained, consisting of black, gray, and golden-agouti young, and indicating, therefore, that the black and the golden-agouti characters kept intact. One of the heterozygotes was back-crossed with the golden-agouti parent and produced the same three coat characters, black, gray, and golden-agouti. The golden-agouti parent, in this case, must have produced some gametes with the chocolate character only, so that black young resulted. (3) The chocolate type, represented by mice having pigment of that color only, breeds true, even if one of the parents contains albinism recessive. Chocolate mice, whether having albinism recessive or not, therefore, contain no other pigment-character. Albinos of two chocolate parents will, on being bred to chocolate mice, produce offspring having only the chocolate-pigment character.

Chocolate mice, bred to albinos of gray parentage, produce gray young. Black young have resulted, in a few cases, from breeding chocolate mice to albinos of mixed ancestry. This fact probably indicates a segregation of the color characters borne by the albino, in such a manner that the black character is present with chocolate, but without yellow, in some of the gametes, and is dominant over the chocolate character of the

gamete with which it unites. In support of this hypothesis, it has been found that these black animals, on being back-crossed with chocolate mice, produce nearly equal numbers of black and of chocolate young.

The gray heterozygotes resulting from the cross of chocolate with albino mice, when interbred, did not produce the expected one-in-four of chocolate mice, but instead golden-agouti and black young were more numerous than those of the chocolate color, and these three classes were together about one-fourth as numerous as the gray. This result is probably due to a resolution of a portion of the gametes of the albinos having the gray character, so that black-chocolate and golden-agouti are present in different gametes. A similar resolution is also indicated by the back-cross of one of the gray heterozygotes with the chocolate parent, for the resulting offspring represented the gray, the black, and the golden-agouti types, but not the chocolate.

(3) Golden-agouti mice, characterized by having the yellow and the chocolate pigments, breed true to their type as a rule, but may give the chocolate type also. Chocolate as well as golden-agouti mice may be obtained by crossing the two types, but it is not yet certain whether this result is due to a resolution of the color of the golden-agouti or whether the latter contains chocolate in a recessive condition.

A cross of golden-agoutis with albino mice coming of mixed ancestry (including gray) resulted for the most part in gray young, though one golden-agouti female produced two black young, when bred to such an albino. These latter probably indicate that the female was producing some gametes with the chocolate character, which, uniting with the gametes from the albino having the black character, gave black young. This hypothesis is supported by the fact that the two black young bred *inter se* gave both black and chocolate offspring, and so must have been heterozygous with respect to the two pigment-characters. The albinos used were of a stock known to produce a proportion of gametes having the black character.

The gray young, resulting from this cross of golden-agouti with albino mice, gave, when interbred, about one-fourth of golden-agouti offspring, indicating that that character became segregated at gamete formation. Except for a single black young, the other progeny were gray.

Back-crossing the gray heterozygotes with golden-agouti animals reproduced the two types only, but the grays were present in slightly more than their expected proportion, although the total number of young was not large.

(4) In general, therefore, unresolved gray is dominant over all of the

other color types employed. Gray may also be produced synthetically by breeding together a black and a golden-agouti animal, for all three of the pigments composing the gray coat are thereby brought together in the young. So far as concerns the pigment-character of the young produced, either parent in this cross may equally well be replaced with an albino derived from parents of the pigment type indicated. Gray should also result from crossing the black type with the pure yellow, or with an albino of pure yellow ancestry, or from a cross between a pure yellow and an albino of black ancestry.

Black, chocolate, and golden-agouti mice as a rule breed true; but black may be a simple dominant over chocolate, and there is some evidence that a similar relation may exist between golden-agouti and chocolate. Both black and golden-agouti agree in consisting partly of chocolate pigment, so that the added recessive chocolate may have no appreciable effect on the appearance of the heterozygous individual.

All three of these color types may arise through a resolution of the compound character, gray. A similar resolution of compound pigment-characters occurs in the case of some plants, as in Mirabilis.

Postscript.

Since the foregoing account was written, the author has seen Cuénot's third report on his experiments in breeding mice. It is gratifying to note that this investigator also finds the character partial albinism in mice to be recessive with respect to total pigmentation. The spotted or partial albino character, he finds, is separately heritable, and may be possessed potentially by an albino. Other albinos may possess the character producing total pigmentation, and both pigmented and albino individuals may be heterozygous with respect to the two coat characters. The results detailed in the present paper, therefore, completely confirm those obtained by Cuénot in regard to the heredity of the spotted character.

Cuénot also describes some experiments in crossing yellow mice with other color varieties, and finds, rather curiously, that the yellow character is dominant over both gray and black. This result indicates a strong individuality for the yellow character and strengthens the belief that the yellow type of mouse is in origin different from the black, chocolate, and golden-agouti types, and may, as Bateson suggests, be derived from another species, perhaps *Mus sylvaticus*.

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